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BULLETIN OF THE
U.S. DEPARTMENT OF AGRICULTURE

No. 71

Contribution from Office of Experiment Stations, A. C. True, Director.
April 30, 1914.

(PROFESSIONAL PAPER.)

THE WET LANDS OF SOUTHERN LOUISIANA AND THEIR DRAINAGE.

By Charles W. Okey, *Drainage Engineer.*

INTRODUCTION.

Louisiana ranks second among the States in the area of swamp land within its borders and in the percentage of its total area that is classed as swamp land. Of a total area of 45,420 square miles, 15,930 square miles, or 35 per cent, are classed as swamp and overflowed land. The drainage of these lands is a public improvement of very great importance to the future wealth and prosperity of the State. Although the magnitude of the task has long been recognized and the tremendous advantage that the reclamation of these lands would bring to the State has been admitted by all concerned, it is only recently that the work of putting the swamp land into condition for cultivation has been attempted on any large scale. A number of conditions are responsible for this delay in the work, among which the following are important:

First, a very large proportion of the swamp lands of the State was at one time subject to overflow by the Mississippi River. The first step in the drainage of these lands was to protect them from river overflow by levees constructed along the main river channels. This phase of the work has been going on in some parts of the State for more than 100 years, and in nearly all parts of the overflowed section since about 1875. It has been carried forward as fast as the funds could be secured for the work. Second, the former abundance of cheap and well-drained agricultural land in this and other parts of the country made these lands unattractive. Third, the necessary State laws were not until recently enacted.

As the above-mentioned obstacles are now in a measure removed, the work of swamp-land drainage is attracting serious and widespread attention. The most active field of drainage operations is at present in the southern portion of the State, and it is here that the Office of Experiment Stations, United States Department of Agriculture, has for about four years been carrying on drainage investigations. The purpose of this work has been: (1) To study the soil, climate, and other natural conditions with special reference to the drainage problems encountered and the value of the land for agricultural purposes when successfully drained. (2) To collect such technical data and to examine

Note.—This bulletin contains information of value to landowners, engineers, and others interested in drainage by pumping, especially of the wet prairies along the Gulf Coast.

such details of present practice as will afford information of value to landowners, and especially to engineers interested in the reclamation of such lands. (3) To disseminate in available form the results of the investigations and to encourage land drainage by emphasizing the benefits to be derived from bringing such lands under cultivation.

The work in this field was started in 1909 by Prof. W. B. Gregory, of Tulane University, New Orleans, and Mr. A. M. Shaw, then a drainage engineer in the employ of this office. It was continued under their direction until early in 1910, when C. W. Okey, drainage engineer, was placed in charge. Certain lines of investigation have been carried forward continuously since 1909, but it has not been possible to give the work uninterrupted personal attention since 1910. At frequent intervals reports have been made of results obtained, and as often as seemed advisable partial reports have been published.[1]

It is the purpose in this bulletin to include all of the salient features of the information so far published and to give also the results of later investigations. Where direct quotations from earlier publications are made, credit will be given, but much of the material contained in the earlier publications and reports will be so interwoven with later and more complete information that no specific mention will be made of its source. The scope of this bulletin is as follows:

First, a description of general conditions in this section of the State, of such a nature and in such detail that persons unfamiliar with this or similar sections of the country will be able to form a fairly accurate idea of the nature of the problems encountered in the successful drainage and cultivation of these swamp lands.

Second, a statement and brief consideration of some of the larger drainage problems encountered, emphasizing the need of more complete cooperation between the various interested parties in the study and solution of such problems.

Third, the results of detailed examinations of a number of drainage districts, reclaimed or in process of reclamation, and a summary of such results.

Fourth, a consideration of the problems involved in land drainage by means of pumps in Louisiana. This discussion might be considered as a continuation of a former bulletin published by this office dealing with pumping in the upper Mississippi River Valley.[2]

LOCATION AND GENERAL CONDITIONS.

As shown by the accompanying map (fig. 1), the area under consideration lies on the immediate Gulf coast. A range of hills running eastward from Baton Rouge, the State capital, to Lake Pontchartrain, forms with the lake the northern boundary of the portion lying east of the Mississippi River. Most of the land in this area is from 1 to 3 feet above sea level, with a very small percentage lying along the river and the larger bayous having an elevation of from 4 to 15 feet above sea level. To the westward, between the Mississippi and the Atchafalaya Rivers, the land gradually rises from sea level along the Gulf to an elevation of perhaps 15 or 20 feet along a line drawn from Baton Rouge to Lafayette, except that in the immediate vicinity of the Atchafalaya River the land is but very little above sea level. As in the area to the east of the Mississippi River, there is in this section a small percentage of higher land along the rivers and bayous. To the westward of the Atchafalaya River there is a strip of swamp land which borders the coast line and which gradually rises from sea level to approximately 10 or 15 feet above, at a distance of 20 or 30 miles inland.

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[1] See especially U. S. Dept. Agr., Office Expt. Stas. Rpt. 1909, p. 415.

[2] U. S. Dept. Agr., Office Expt. Stas. Bul. 243.

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FIG. 1—Map of Southern Louisiana, showing wet lands, and heights of storm tide on September 20, 1909.

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The area of the district is roughly 12,000 square miles, of which amount about 10 per cent is high enough to be drained by gravity, this representing the percentage of the total area that is already drained and under cultivation. The remainder is so low that artificial means must be used to get an outlet for drainage water. The area shown in figure 1 is about one-fourth that of the entire State, yet the tract contains nearly two-thirds of the State's swamp land.

Throughout the entire district are connecting lakes and bayous, many of which are navigable with boats of considerable draft and beam. The total length of such navigable streams is, roughly, 1,600 miles. The main waterway is the Mississippi River. The Atchafalaya River has lately been opened to deep-water navigation through a dredged channel at its mouth, and vessels of a draft of not more than 20 feet can safely enter it. This system of waterways insures excellent water transportation to the entire district, in addition to the facilities afforded by the railroads, a number of which traverse the district.

Besides the cities of New Orleans and Baton Rouge, there are several considerable towns in the district, including Morgan City, with a population of about 5,000; Houma, 5,000; Donaldsonville, 4,000; New Iberia, 7,500; Lafayette, 6,400; and Crowley, 5,000. Lake Charles, the principal railroad center of the western part of the State, has a population of 12,000.

The very small percentage of this area that is under cultivation is worked very intensively and supports a population of over 200 to the square mile. While the principal industry of the whole region is agriculture, the wealth derived from other sources, including sea food, lumber, oil, gas, salt, and sulphur, is almost as great.

CLIMATE.

Temperature.

The United States Weather Bureau has issued summaries of the climatological data of the United States by sections. Southern Louisiana is designated as section 45, and from the summary for this section[1] the following is taken:

Climatic conditions over southern Louisiana are marine in character; the proximity of the Gulf of Mexico and the numerous streams and lakes of this region all conspire to modify the temperature conditions and prevent sudden changes therein, and extremely warm weather in summer and severe cold in winter seldom occur. Southerly winds from the Gulf temper the climate and prevent, both in winter and summer, extremes that might otherwise occur. The annual mean temperature is 67.9° F. January is the coldest month, with a mean temperature of 52.4°, while July and August are both warm, with mean temperatures of 81.6° and 81.7°, respectively. The highest annual mean temperature is 70.1° at Burrwood, at the mouth of the Mississippi River, and the lowest 66.4° at Cheneyville. The highest monthly mean temperature is 83° at Lawrence in August, and the lowest 49.6° at Cheneyville in January. The range in the annual mean temperature is very slight, and within 100 miles of the coast amounts to only 1°. After passing inland the change is more abrupt, and over the second hundred miles the gradients are steeper than over any other portion of the State, where the fall in the annual mean temperature amounts to 2° in about 100 miles. The stations with the same mean temperature in July and August are situated in the piney woods and the prairie section. The coast marsh and the alluvial region have the highest mean temperature in July. The greatest difference between the July and the August mean temperature amounts to but 0.7°. January averages about 1° to 2° colder than December and February. The range in the mean temperature between the hottest and coldest months is 29.3°.

There is a narrow strip along the coast where the temperature has probably never reached 100°, and even as far north as New Orleans it has not reached this degree except in two years, 1901 and 1909. The highest temperature recorded in the section is 108° at Creneyville, Rapides Parish. The extreme

[1] U. S. Dept. Agr., Weather Bureau Bul. W, sec. 45.

range in maximum temperature amounts to 11°. New Orleans may be taken as a representative station for the southern portion of this section. The maximum temperature has exceeded 100° in but one year, 1901, when 102° was recorded, although a maximum of 100° was recorded in 1909. The temperature reaches 90° every year, but there have been 14 years out of the last 39 in which the temperature did not reach as high as 95°. During 36 years there have been only 78 days when the maximum temperature rose to or above 95° at New Orleans.

The minimum temperatures of this section of Louisiana range from 1° at Amite and Hammond to 19° at Lakeside, the range in minimum temperature being 18°. During 36 years the minimum temperature has been below 32° at New Orleans only 131 days, or an average of less than four times a year. The temperature at New Orleans has fallen below 20° during a period of 36 years in only 4 years, as follows: 1886, 15°; 1895, 16°; 1899, 7°; and in 1905, 18°. Freezing temperatures occur to the Gulf coast in the months of January and February, but owing to the season of the year and the ample warnings given by the bureau to interests affected these frosts seldom cause any loss.

It has been found that the recording stations in the country give somewhat lower mean temperatures and also lower minimum temperatures than stations situated in large cities, as New Orleans. Houma, in Terrebonne Parish, is chosen as representing average conditions in the country in the alluvial sections, and Cameron, in Cameron Parish, as being typical of the coastal plain region in southwest Louisiana. The following frost and temperature data are taken from the records of the Weather Bureau:

Average earliest and latest dates of killing frosts at Cameron, Houma, and New Orleans, La.

Station.	Number of years' record.	Average date first killing frost in autumn.	Average date last killing frost in spring.	Earliest date killing frost in autumn.	Latest date killing frost in spring.
Cameron	15	Nov. 26	Feb. 22	Oct. 25	Mar. 20
Houma	18	Nov. 20	Feb. 28	....do...	Mar. 25
New Orleans	37	Dec. 10	Feb. 3	Nov. 11	Mar. 27

Highest, lowest, and monthly and annual mean temperatures, in degrees Fahrenheit, at Cameron, Houma, and New Orleans, La.

HIGHEST TEMPERATURES.

Station.	Number of years' record.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Highest.
Cameron	16	85	101	89	94	101	101	103	102	104	100	89	87	104
Houma	19	81	84	88	92	95	100	102	99	98	93	89	82	102
New Orleans	39	82	82	86	89	94	98	102	100	96	94	85	83	102

LOWEST TEMPERATURES.

Cameron	16	17	13	14	35	39	44	61	45	49	30	20	13	13
Houma	19	17	5	25	30	42	51	58	56	44	32	25	10	5
New Orleans	39	15	7	30	38	52	58	66	63	55	40	29	20	7

MONTHLY AND ANNUAL MEAN TEMPERATURES.

Cameron	14	51.7	53.9	62.6	69.3	75.2	80.7	81.8	81.9	79.0	69.4	61.8	54.9	68.5
Houma	18	54.3	55.3	63.4	68.8	75.3	80.3	81.2	81.4	78.5	67.8	61.0	54.1	68.4
New Orleans	39	53.9	56.8	63.1	68.7	75.1	80.6	82.3	82.1	78.8	70.3	61.6	55.4	69.1

Rainfall.

In regard to the yearly rainfall the Weather Bureau summary of the climatological data for section 45 says:

There is a gradual and well-defined decrease in precipitation from the eastern toward the western portion of this section. The average annual precipitation is 55.76 inches, and ranges from 48.36 inches at Lakeside, Cameron Parish, to 63.02 inches at Amite, Tangipahoa Parish. The precipitation is practically all in the form of rain and is well distributed throughout the year. Snow occurs on an average of once in three to five years, and disappears soon after having fallen. Although droughts occur, they are seldom long continued, and are not so serious as in regions where the level of the ground water is so much farther below the surface of the earth. June and July are usually the wettest, and October and November the driest months.

Rain falls about once in three days. The average number of rainy days is 108 in the eastern and from 77 to 80 in the western portion of this section.

The following rainfall data are taken from the Weather Bureau records:

Monthly and annual mean rainfall, in inches, at Cameron, New Orleans, and Houma, La.

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Cameron	3.67	3.34	3.39	3.61	3.61	5.60	7.57	4.04	5.44	2.88	4.12	3.28	50.55
New Orleans	4.54	4.28	4.56	4.53	4.06	5.39	6.53	5.65	4.49	3.25	3.81	4.54	55.63
Houma	3.45	4.78	3.52	4.29	3.59	5.98	8.92	6.43	5.92	3.00	2.73	4.31	56.92

The rainfall in this section is more or less tropical in character, especially during the summer months. The rains are nearly always purely local during the summer, and the amount, both daily and monthly, may vary greatly for stations separated by only a few miles. Thus we have a monthly total in August, 1911, of 28.5 inches at Donaldsonville, at the northern edge of this section, and but 12.27 inches at Houma, only about 40 miles away.

The United States Weather Bureau records at the New Orleans station show that there have been 43 storms in the past 22 years, during which the precipitation in 24 hours exceeded 3 inches. These storms are classified as to their intensity as follows:

43 rains exceeding 3 inches in 24 hours.
19 rains exceeding 4 inches in 24 hours.
7 rains exceeding 5 inches in 24 hours.
3 rains exceeding 6 inches in 24 hours.
2 rains exceeding 7 inches in 24 hours.
2 rains exceeding 8 inches in 24 hours.
0 rains exceeding 9 inches in 24 hours.

Health Conditions.

As regards the healthfulness of this climate the Bureau of Soils says:[1]

A most serious check to the attraction of a desirable class of immigrants to this section is the impression which has gotten abroad as to its unhealthfulness. That this idea had some foundation in the past can not be denied, but such a condemnation can not now be applied to the State as a whole or to this particular vicinity. The records of the medical board of New Orleans show that the city has an excellent health record for a city of its size. * * * Outside of the city sanitary conditions are naturally much better. The dwellings of both the owners and the tenants of the plantations stand on the higher land along the Mississippi River, where there is adequate natural drainage. Not-

[1] U. S. Dept. Agr., Field Operations of the Bureau of Soils, 1903, pp. 443, 444.

withstanding the proximity of the swamps and standing water, malaria, though occasionally occurring, is not dreaded. Until within the last few years epidemics of yellow fever caused frequent alarm, but this disease has now been thoroughly eradicated, and with the methods of treating the disease and preventing its spread it is not to be dreaded as formerly, even if it should again appear.

Since it has been demonstrated that malaria, like yellow fever, can be transmitted to man only through the bite of a certain species of mosquito, it may be expected that drainage, which destroys the breeding places of these pests, will result in a decrease in whatever malaria may now exist. As a matter of fact malarial fever is very rare on the immediate coast line, and the health of people from the North seems to be fully as good as that enjoyed by the natives.

SOILS.

The area under discussion contains soils that are peculiar to the section and these are now for the first time being drained and cultivated. In the following section are set forth the results of first-hand investigations along with the classification and general descriptive matter taken from publications of the United States Bureau of Soils.

Area East of the Atchafalaya River.

ORIGIN AND FORMATION OF SOILS.

The soil of the area east of the Atchafalaya River and in parts of St. Mary, Iberia, and St. Martin Parishes is of alluvial origin and is largely the result of deposits made by the Mississippi River and its branches. It has been built up from a depth of several thousand feet to the present elevation above the Gulf. In the very newest portions of the Delta at Port Eads, at the mouth of the river, a considerable subsidence of the land is yet going on, the measured rate being about 0.11 foot per year. That this subsidence is due to a compacting of the newer deposits is shown by the fact that permanent bench marks along the Mississippi River record a decreasing settlement as the distance from the mouth of the river increases. Except in this relatively small area, near the mouth of the river, the remainder of this section of the State shows no change in elevation. As is typical of delta regions, ridges of sandy soil are found along the main river channel and along its branching outlets. The manner in which these ridges were formed is well brought out in the following, from A Preliminary Report upon the Bluff and Mississippi Alluvial Lands of Louisiana, by W. W. Clendenin.[1]

With every flood the river now overflows its flood plain and deposits much of the sediment from its headwaters. As with a slight increase in velocity the transporting power is vastly increased, so with a slight checking of velocity, as occurs over the flood plain outside of channel, deposit takes place. As the greatest decrease in velocity takes place near the channel, there the heaviest and coarsest sediment is deposited, and in greatest quantity. The river banks are thus built higher by each flood and a system of natural levees is produced. There is thus a marked difference in the "front lands" and the "back lands" along the river. The former are higher and coarser textured than the latter, and therefore much more easily cultivated and drained.

Drainage from the very channel margin is away from the river, and unless forced by the topography of the land, will not reach the river proper, but unite with some outlet of the river produced during some extraordinary flood period and kept open by the escape of water during ordinary periodic flood stages. As the feeders of the river are called tributaries, these outlets have not inaptly been styled distributaries.

[1] Louisiana Stas. Rpt. Geology and Agriculture, Pt. IV, p. 263.

Since practically all land in the delta region is now protected from overflow by levees along the Mississippi River, and as overflow is now very rare, all building up of the low marshlands has been checked. However, at the mouth of the Mississippi River, deposition of material is continually taking place.

Even before the construction of the artificial levee system, there was no raising of the general level of the marshes during periods of normal flow and probably little sedimentation of the river bed excepting at its mouth, the most of the material which was carried in suspension to the lower portion of the river being carried out and deposited in the Gulf. As the river rose, however, the waters constantly sought additional outlets through the various bayous of the delta country. At times of extreme high water there was a general breaking over the banks of the river and its outlets. It is probable that the most of the building up of the lands above sea level has been done at such times.[1]

The above statements show that while the Mississippi River and its various distributaries are continually extending themselves through deposition at their mouths, it was only at times of overflow that the ridges along the channels were raised or widened. The peculiar branched nature of the Delta, with bodies of land extending fingerlike into the Gulf, with open spaces of water between, is also thus accounted for. As these ridges gradually widened they approached each other, thus forming lakes and bayous. Tidal action usually kept these ridges from inclosing the open water between them, and heavy and prevailing winds would no doubt often change their character and direction. It is a noticeable fact that the trend of the majority of the waterways in this section is toward the southeast. As the prevailing winds are from the southeast, and as the usual Gulf currents flow from that direction, most of the sediment was deposited on the western side of the channel. As a result the deeper water always remained to the eastward, and the deposition on the western shore continually forced the channel to the eastward. It is reasonably certain that the large inland lakes, such as Lake Des Allemands and Lake Salvador, were inclosed in this manner.

The fact that the silt-bearing capacity of water is directly dependent upon the velocity is clearly demonstrated by observing the natural embankments formed by streams of various sizes. In the case of smaller streams when the water overflows, its force is soon spent and the silt is quickly deposited near the stream, forming narrow ridges with steep side slopes, while those formed by large streams are broad with slight slopes. Three typical examples, showing this difference and the manner in which the land surface has been raised on the marshes are given in figure 2, A, B, and C.

The sections were taken as follows:

A—From the right bank of the Mississippi River across the Willswood plantation, about 10 miles above New Orleans. This section is about 2 miles long and a part of the lands crossed have been under cultivation for a great many years, while those farthest from the river were reclaimed only 12 or 15 years ago. The lowering of the surface of the cultivated and drained fields due to the shrinkage of humus soils is here well illustrated. There are many examples of highlands having been built up for much greater distances from the river than this, but as such accretions are indirect, on account of being formed by a number of small bayous or temporarily contracted areas of overflow which assisted in maintaining the velocity, these have not been considered as being typical.

B—The right bank of Bayou Lafourche at Lockport, extending back through the village of Lockport and beyond to Lake Fields. Until 1903 Bayou Lafourche served as an overflow outlet for the Mississippi River, the opening at Donaldsonville not having been permanently closed until that year.

C—This is a very small bayou extending to about 4 miles west of Lockport. The abrupt rise of the ridge from the surrounding marshes is especially noticeable and is characteristic of smaller bayous.

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[1] Manuscript report of A. M. Shaw.

Important exceptions to the foregoing general statement as to the relation between the size of bayous and the ridges built by them are frequently found.

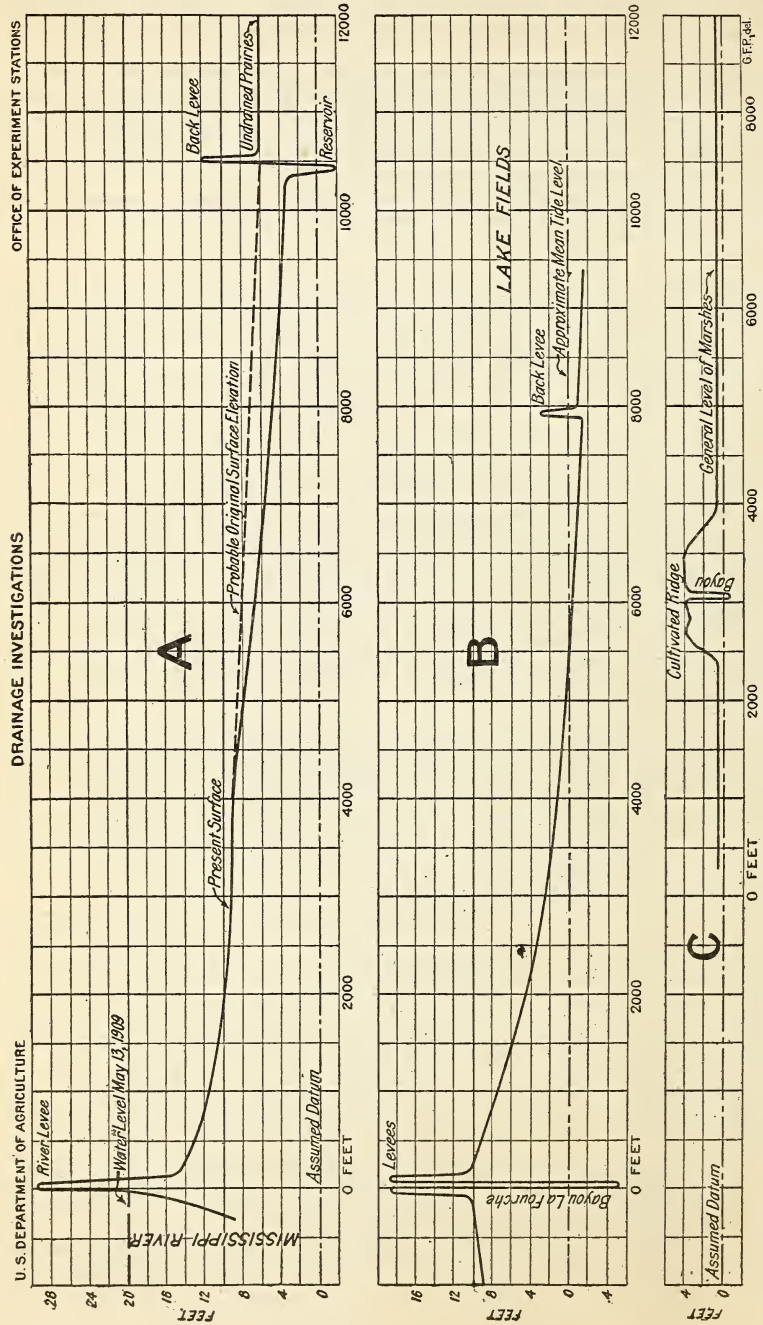


FIG. 2.—Typical examples of Louisiana marshland formation: A, Profile through area No. 1; B, section through area No. 2; C, formation caused by small bayou near Lockport.

Prominent among those are the Bayou L'Ourse, in the southeastern part of Lafourche Parish, and the Wax and Little Wax Bayous, in St. Mary Parish.

Bayou L'Ourse is an insignificant stream, occupying the center of a long and important ridge. It is probable that at one time this bayou served as an outlet for the Lafourche or possibly of some predecessor of the latter bayou, draining in a more easterly direction through Bayou Blue, Lake Fields, and Long Lake. Wax and Little Wax Bayous are streams of erosion rather than of sedimentation and have been formed wholly or in part by the action of storms and the tidal flow which is quite strong along this portion of the coast. As a result, the bayous are bordered by the marsh or by very low ridges. Both streams are from 10 to 50 feet in depth and 100 to 200 feet in width.[1]

In addition to the above, Bayous Terrebonne and Black, in Terrebonne Parish, are typical examples of the sedimentation type, while Bayou des Allemands, the connection between Lake Des Allemands and Lake Salvador, is an excellent illustration of the tidal-erosion type.

From the foregoing it may be seen that the chief difference between the various types of soils is the variation in fineness of material, rather than difference in chemical composition.

CLASSIFICATION AND EXTENT OF SOILS.

The various types of soil grade imperceptibly into one another, but the following classifications have been made by the Bureau of Soils of this department: Yazoo sandy loam, Yazoo loam, Yazoo clay, Sharkey clay, muck, and Galveston clay.

The first three classes are ridge soils and are limited in extent, forming a very small percentage of the total area. These soils have sufficient elevation to drain naturally, and as they are practically all well drained and cultivated no discussion of them will be given. For additional information the reader is referred to the publications of the Bureau of Soils.

The last three classes include practically all the undrained soils of this section. The Bureau of Soils says of this first type:[2]

The Sharkey clay is the heaviest soil of the New Orleans area. It is the most extensive type and as only a small proportion of it is under cultivation, the subject of the reclamation of the large unused area is attracting considerable attention.

The soil is a heavy black clay to a depth of 5 or 6 inches. The dark color is due to the large content of organic matter which has been derived from the heavy growth of vegetation as the clay was slowly deposited. This decayed vegetation has had a marked beneficial effect on the structure of the soil by causing it to break under the plow into little blocks and to assume a much more favorable condition than is usually possible with this type. The subsoil is a brown or drab waxy clay of a most impervious and tenacious character. The percentage of organic matter is much smaller than that of the soil.

The Sharkey clay shrinks greatly upon drying, and the surface of a drying field is always checked by large sun cracks.

The Sharkey clay occupies the entire land surface of the area, with the exception of narrow strips along the rivers and bayous, where the swifter overflow waters have built up natural levees of coarser sediments, and excepting also considerable areas where it has been covered so completely by decayed vegetation that a muck type has been established. * * * The Sharkey clay areas are for the most part forested. The exceptions are those comparatively small areas in cultivation and the treeless prairies which cover a considerable area in the southern part of the present survey. In the very wet, poorly drained tracts there is an almost impenetrable growth of cypress, willow, maple, water oak, and sometimes ash. On the better drained portions the woods are more open and the palmetto flourishes near the border.

Of the soil classed as muck, the Bureau of Soils says:[3]

Between the Mississippi River and Lake Pontchartrain are extensive areas where the dense growth of vegetation has decayed and accumulated on the sur-

[1] Manuscript report of A. M. Shaw.

[2] U. S. Dept. Agr., Field Operations of the Bureau of Soils, 1903, p. 451.

[3] U. S. Dept. Agr., Field Operations of the Bureau of Soils, 1903, pp. 452, 453.

face of the Sharkey clay to a depth of from 1 foot to more than 3 feet. This more or less decomposed mass is made up of the trunks and leaves of trees, but more largely of the rank weeds and grasses which flourish in this locality.

The extensive tracts covered by the muck are poorly drained and almost impenetrable. The only places where this type can be seen under any favorable conditions of drainage are between the drainage canals which lead from New Orleans to Lake Pontchartrain. Clearings have been made and it has been demonstrated that the muck can be reclaimed, but so far none of it has been cultivated. The muck in many of the localities in which it was observed is finely divided and well decomposed and should be well adapted to the cultivation of those crops which thrive on the peaty soils.

Of the type called Galveston clay the Bureau of Soils says:[1]

The Galveston clay consists of a mucky mass of vegetation in various stages of decay, interspersed with a fine clay of drab color. Along the borders of the marshy prairies covered by this type the soil closely approaches in texture the Sharkey clay, and passes into a subsoil similar to that of the Sharkey clay at lower depths, but the lower lying strips nearer the bayous are little more than peat bogs to a depth of more than 3 feet.

The Galveston clay forms a broad border along the Bayous des Allemands, opening out a short distance above the town of Des Allemands to a width of several miles outside of the present area, with an arm extending northward toward the town of Hahnville. The latter extension follows the course of a sluggish bayou with its many ramifications through the marsh.

The topography of the type is that of a low marsh but little elevated above sea level. Water stands over much of the surface at all times in pools and channels and renders the marsh almost impenetrable except by boat. * * * The areas occupied by this type are entirely treeless and devoid of other vegetation, except sparse marsh grasses which have little value for grazing. This absence of vegetation, in such contrast to the dense swamp growth on the Sharkey clay, is due largely to the brackish nature of the water which ascends the bayous at high tide, and perhaps in part to the peaty nature of the soil, with its poor drainage.

From the foregoing it will be seen that the type called Galveston clay is a combination of the so-called Sharkey clay with muck, with the former as a subsoil. Over the whole of the wet prairie section of the Delta this type of soil is found, the muck varying in thickness from a few inches to several feet. The tracts of land that are now being reclaimed in southern Louisiana all contain more or less of this muck land, and many of the districts are entirely covered by it.

DRAINAGE CHARACTERISTICS OF SOILS.

As the ultimate success of most of the reclamation districts of this section will depend on the successful drainage and cultivation of these muck lands, a rather detailed study of them was made. In investigating these soils it was the endeavor to get a careful description of their physical characteristics, to find the percentage of water by volume that they would contain when in good condition for growing crops, and to ascertain the amount of water they would hold when completely saturated.

The muck is a mass of vegetation in varying stages of decay and contains varying amounts of river silt. In character it differs according to the kind of vegetation from which it was derived; thus the muck of the cypress swamp is much darker and less fibrous than the muck or turf of the open grass-covered prairie. Also, according to stage of decay, it may be tough and fibrous and able to bear the weight of a man, or it may be soft and even semifluid if considerable water be present. Being the result of growth rather than of deposit, it has been formed in layers, the depth of which depends largely on the time involved. When a layer of vegetation is covered with a heavy layer of silt all

[1] U. S. Dept. Agr., Field Operations of the Bureau of Soils, 1903, p. 453.

addition to the former ceases, and if conditions are favorable, a new layer of vegetation is formed on the silt above. Thus we have strata of muck varying in thickness from an inch to several feet, with intermediate strata of silt of depths of from 1 inch to perhaps 2 feet. About half of the waterways that extend through these swamps are streams of tidal erosion, and along these streams the high ridges of river silt are absent and the muck is especially deep. Bayou des Allemands, Wax Bayou, and Little Wax Bayou are streams of this character.

The samples of muck examined were taken at just sufficient depth below the surface to insure the optimum percentage of water—i. e., the amount of moisture considered by local plantation owners to be the best for the growth of general field crops. No samples were taken immediately after a rain nor after a long dry period. At the time of taking the samples a description of each field was made, including depth of water table, length of time the field had been drained and cultivated, time since last rainfall, character of original vegetation, nature of present crop, and other conditions peculiar to the tract in question.

The following tables show the results of tests made during the spring of 1910:

Results of soil tests on area No. 3, Raceland, La.

No. of sample.	Depth of sample.	Number of days since rain.	Weight per cubic foot.			Water in soil by volume.			Depth of water table.
			Normal.	Saturated.	Dry.	Normal.	Saturated.	Gain.	
Turf:	*Inches.*		*Lbs.*	*Lbs.*	*Lbs.*	*Per ct.*	*Per ct.*	*Per ct.*	*Inches.*
12	4–10	7	45.8	61.5	7.0	62.1	87.2	25.1	18
13	4–10	7	54.4	.....	8.7	73.1	.....	.....	18
22	4–10	10	44.0	.....	9.4	55.4	.....	.....	20
23	4–10	10	45.8	62.3	12.4	53.4	79.8	26.4	20
24	5–10	10	43.9	.....	10.7	53.1	.....	.....	20
25	5–10	10	46.7	60.7	14.0	52.3	74.7	22.4	20
30	3– 8	14	41.3	61.5	7.6	53.0	86.2	32.3	20
31	3– 8	14	41.3	.....	7.9	53.4	.....	.....	20
32	6–10	14	51.2	.....	7.9	69.4	.....	.....	22
33	6–10	14	47.3	57.6	7.3	64.0	80.5	16.5	22
Turf with silt:									
10	8–12	7	57.9	71.3	21.2	58.7	80.5	21.4	20
11	8–12	7	61.4	.....	22.8	61.8	.....	.....	20
14	12–16	7	64.0	77.6	29.5	55.2	77.0	21.8	18
15	12–16	7	66.0	.....	30.0	57.5	.....	.....	18
16[1]	3– 7	7	53.7	67.9	14.9	62.0	84.8	22.8	20
17[1]	3– 7	7	56.2	.....	16.9	62.9	.....	.....	20
26[1]	3– 8	10	54.8	.....	16.9	60.6	.....	.....	24
27[1]	3– 8	10	46.7	64.9	8.7	60.8	89.9	29.1	24

[1] Turf and silt after being mixed by two years of cultivation.

The above samples were taken from the soil on area No. 3, which lies about 5 miles from Bayou La Fourche and the same distance from the town of Raceland. This district is a part of the open grass-covered prairie and has been well drained for about three years. Its elevation is perhaps a foot above mean tide level, and the soil probably would be classed as "Galveston clay." The fields from which these samples were taken were in cultivation in 1909 and were planted to corn or sugar cane in the spring of 1910. The original vegetation was a wild prairie grass, locally called "paille fina." It was from this grass that the muck or turf was formed. The soil of the top 4 to 5 inches was quite soft and dry, having been recently cultivated. Just below the depth of cultivation the soil became moist, and when compressed water would drip from it. The muck here was of a dark-brown color and was very light and spongy; after drying it became much darker in color. It seemed to be a mass of partially decayed grass and grass roots, and had very little, if any, silt in its composition. The

depth of the muck on this tract varied from 6 to 18 inches. Below this came a layer of mixed turf and silt about 1 foot in thickness, and from here on down to a great depth occurred pure silt which would be classed as "Sharkey clay." The ground-water level stood a little less than 2 feet below the surface, which is about the average depth of drainage secured on this tract. The first 10 samples in the table were taken from the layer of pure turf, the next four, Nos. 10, 11, 14, and 15, from the layer of mixed silt and vegetation just under the layer of pure turf, and the last four, Nos. 16, 17, 26, and 27, from a field on the same tract that had been cultivated for two years, but had not been cultivated in 1910 when the samples were taken. The condition of these last four samples shows the result of plowing deeply, thus mixing the silt and the pure turf, and gives an idea of the conditions that may be expected after the fields have been cultivated for a time.

The following table gives the results of tests of the muck on area No. 4, which lies a little farther out from Bayou La Fourche than does area No. 3.

Results of soil tests on area No. 4, Raceland, La.

No. of sample.	Depth of sample.	Number of days since rain.	Weight per cubic foot.			Water in soil by volume.			Depth of water table.
			Normal.	Saturated.	Dry.	Normal.	Saturated.	Gain.	
Muck:	*Inches.*		*Lbs.*	*Lbs.*	*Lbs.*	*Per ct.*	*Per ct.*	*Per ct.*	*Inches.*
28	4–9	10	48.9	.....	10.0	62.2	.....	.....	18
29	4–9	10	51.2	63.7	10.8	64.7	84.7	20.0	18
34[1]	3–8	14	59.2	.....	10.0	78.7	.....	.....	12
35[1]	3–8	14	58.2	63.8	10.2	76.8	85.8	9.0	12

[1] Samples 34 and 35 were undoubtedly too moist for optimum percentage of moisture.

The conditions on area No. 4 were similar to those on area No. 3, except that the land on No. 4 had been well drained only eight months and had not been cultivated. The top of the muck was covered to a depth of about 4 inches with a tough sod full of heavy grass roots, but below this sod these roots tapered out to very fine rootlets. The samples contained pure turf, which was very similar to samples 12 to 33, inclusive, of area No. 3.

The samples recorded in the following table were taken from area No. 2, which lies about 1 mile back from Bayou La Fourche, near Lockport, La.

Results of soil tests on area No. 2, Lockport, La.

No. of sample.	Depth of sample.	Number of days since rain.	Weight per cubic foot.			Water in soil by volume.			Depth of water table.
			Normal.	Saturated.	Dry.	Normal.	Saturated.	Gain.	
Muck:	*Inches.*		*Lbs.*	*Lbs.*	*Lbs.*	*Per ct.*	*Per ct.*	*Per ct.*	*Inches.*
18	10–15	4	54.4	.....	21.9	52.0	.....	.....	22
20	8–13	4	52.0	.....	13.4	61.8	.....	.....	22
40	7–12	14	52.9	73.0	14.0	62.2	94.4	32.2	26
42	8–13	14	52.0	61.5	10.7	66.1	81.3	15.2	22
Silt:									
19	3– 7	4	112.0	.....	88.6	37.5	.....	.....	24
21	2– 7	4	80.0	.....	48.3	50.7	.....	.....	24
41	2– 7	14	74.8	85.6	47.0	44.5	61.8	17.3	26
43	3– 7	14	111.5	.....	81.9	47.4	.....	.....	26

This tract was a part of the grass-covered prairie which contained a number of scattering groves of small willows. It had been cleared and drained for about five years. Its elevation above mean tide level is about 1 foot. The top soil is a layer of almost pure silt which had been laid down on a layer of muck at a comparatively recent date. The layer of silt varies from 6 to 10 inches and the layer of vegetation is perhaps 12 inches in depth. Below this turf is a deposit of pure silt extending to a great depth. The turf or muck in this tract is perhaps older than that of area No. 3; it seems to have been formed from the same kind of vegetation but it is heavier and much darker than that of the latter district. This is probably due to the weight of the layer of silt which had been deposited on it. The ground had been cultivated in 1910 and the part moved by cultivation was quite hard and dry; however, this cultivation did not reach below the layer of silt, into the muck. The first four samples were taken from the layer of muck, while the next four were taken from the silt overlying the muck. The object of testing both layers of soil was to get an idea of the combined water capacity of the two varieties, for many of the plantations have a mixed soil much like that of area No. 2.

The samples recorded in the following table were taken in Bayou La Fourche sandy loam near Lockport and about one-fourth mile back from the bayou.

Results of soil tests near Lockport, La.

No. of sample.	Depth of sample.	Number of days since rain.	Weight per cubic foot.		Water in soil by volume.	Depth of water table.
			As taken.	Dry.		
Sandy loam:	*Inches.*		*Pounds.*	*Pounds.*	*Per cent.*	*Inches.*
36	3- 8	14	105.9	81.2	39.5	40
37	3- 8	14	105.4	80.6	39.7	40
38	6–11	14	105.9	75.4	48.8	40
39	6–11	14	105.4	78.1	43.7	40

The soil in this tract is representative of the average soil conditions in the bayou-front plantations. It is also of much the same nature as the ridges of silt that occur in many of the turf or muck lands. The soil has been cultivated for a great many years and little vegetable matter was present. It had already been cultivated in 1910 when the samples were taken. The ground was quite moist to the touch, but was perhaps a little drier than usual. The soil was much the same to a very great depth. The tests were made for the purpose of comparison with the tests of the muck.

It will be noted by comparing samples 40 and 42, in the summary of results of soil tests in area No. 2, with samples 36 to 39, inclusive, taken near Lockport, that the muck soil seems to be more retentive of moisture than the sandy loam of the bayou ridge. The samples of each class of soil were taken at approximately the same depth and on the same date, yet the muck contained nearly 50 per cent more water than the sandy loam. Later in this same season, which was unusually dry, the crops on the muck soil withstood the effects of the drought better than those on the sandy ridge soil.

In general, the layers of turf or muck of southern Louisiana are quite similar in character to those of other swamp regions of the United States, but having been formed on an alluvial deposit and in many cases mixed with silt, the turf after a few years of cultivation works up into a most excellent soil, which is well balanced in chemical composition. This is proven by the excellent yields of both truck and general field crops on such lands near Lockport and

Raceland. The muck of the cultivated fields has a greater density and a darker color than that where the land is undrained and uncultivated. In its original state the pure turf is a light brown, but as it dries and decays it becomes darker and finally is almost black. When first drained it is very light and spongy and when plowed breaks up into rather large pieces, sometimes as much as a foot square, which are pushed ahead of the plow instead of being turned in a furrow. After the second year of cultivation the muck loses its fibrous nature and resembles old sawdust in texture, although being a little darker in color. As cultivation continues the muck mixes more and more with the underlying silt and a much heavier and more impervious soil results.

As such soils dry out and decay they shrink and settle to a considerable degree. In the tests made the average shrinkage of the muck, due to drying alone, was a little over 60 per cent. In average field conditions the shrinkage would never reach this figure, due to drying alone, for the soil would never become as dry as the samples tested. However, on area No. 1 (fully described in succeeding pages) the lowering of the surface of the land by drying and decay after 10 years of cultivation has amounted to about 2½ feet. Samples of soil, once thoroughly dried, would not resume their former volume even when immersed in water for 12 days, and would absorb only 35 per cent of their former volume of water; while originally, when in average condition for growing crops, they had held about 65 per cent of water by volume.

In the reclaiming of turf lands of this charatcer there is always more or less danger that the muck will burn. On some of the newer plantations trouble has been experienced in burning off the growths of weeds and grass that covered the muck. This burning off can be done with safety only when the muck is still wet from a recent rain. During the spring of 1910, which was the driest in southern Louisiana since Government weather records have been kept in the State, the muck began to burn on area No. 4, near Raceland. This tract had been drained but about eight months. A rain of three-fourths of an inch failed to extinguish the fire. It became necessary to dig a ditch around the fire deep enough to reach to the silt below. This method of checking fire is practicable and efficient if it is adopted soon enough.

The danger of the burning of any considerable area of the reclaimed land is very remote. The system adopted in reclaiming this land—that of dividing it up into comparatively small levee districts—would limit the extent of the fire, and the division of the districts themselves into small areas by the lateral ditches makes it impossible for the whole of any plantation to be in great danger from fire. The danger from extensive burning to the muck of unreclaimed swamp land is not great even when the muck is very dry, for the ridges of river silt which occur at frequent intervals would serve as effectual checks to any great progress of the fire. Even if the muck be burned from a tract of land the underlying silt makes a very excellent although a somewhat heavy and impervious soil.

Area West of the Atchafalaya River.

ORIGIN AND FORMATION OF SOILS.

Most of the land to the westward of the Atchafalaya River, except as previously noted, is of different origin and character from that of the area just described.

As most of the land of this section consists of recent coastal plain deposits rather than of Mississippi River alluvium, the surface conditions are somewhat different from those encountered in the eastern or delta section of the State. Instead of a succession of ridges and shallow lakes such as occur in the delta

section we have a coastal plain gradually rising from south to north. Along the immediate coast line there is a more or less unbroken sandy ridge through which the local rivers have cut channels. Immediately in the rear of the ridges are stretches of salt marsh very little above sea level, but which gradually rise to the north so that at a distance of some 5 to 10 miles inland they become fresh-water marsh. The larger streams, such as the Mermentau, the Calcasieu, and the Sabine are still depositing alluvium, and since the coast line was elevated these streams have considerably extended the land adjoining them. As the waters of these outlets are very sluggish and are not heavily loaded with silt they have not built up large ridges along the immediate river banks. The alluvial portion is nearly level and the strips of alluvial land along the channels gradually widen as the streams approach the Gulf. These alluvial strips are still in process of formation and of elevation by deposition, since at each high water the adjoining lands are flooded, the rivers not having been leveed.

CLASSIFICATION AND EXTENT OF SOILS.

As before stated, the Bureau of Soils has not made surveys of this section, but has examined and classified the soils immediately north of it. These various clays, clay loams, silt loams, and sandy loams, are described in detail in publications of that bureau.[1] Toward the Gulf the above-enumerated soils are overlaid with muck and alluvial deposits and thus become subsoils.

The lands of this section might be divided into two main divisions, as indicated in the paragraphs on origin and formation: (1) The general wet prairie land, with a comparatively shallow deposit of silt and muck on the surface; and (2) the strips of alluvial land along the river channels or streams. The first class includes the great bulk of the lands of this section. As noted above, the subsoils of this portion are the solid loams, etc., of the higher land, thus affording a solid foundation which is quite different from the soft yielding alluvial silt of the Mississippi Delta swamps. Overlying this subsoil occurs a shallow deposit of partly alluvial silt caused by local erosion and weathering. On the higher and better drained portions there is little or no muck on the surface, although the silt of the top 6 inches is rich in vegetable matter due to the decay of the grasses that grow on these sections. These portions are covered with water only during the rainy season, and during times of long drought ordinary wagons can be driven over them quite safely. Toward the south, however, the land is water-covered practically all of the time, and a layer of muck has formed from decaying prairie grass. In the essential characteristics this muck is very similar to that of the Mississippi Delta section. It averages from 6 to 18 inches in thickness, although in low depressions and shallow bayous it may be several feet deep. Owing to the absence of any extensively silt-bearing streams the muck of these wide level prairie sections is composed almost entirely of vegetable matter, and its dry weight is less than that of the average muck of the delta section. This, however, should not be an undesirable feature, as most of it is so shallow that the cultivation will soon extend into the silt below. As the coast line is approached, as noted before, the marsh becomes salt, but it is covered with practically the same depth of muck. In various places in this section there are broad zones where the silt deposit between the muck and the underlying subsoil is quite deep, perhaps 3 or 4 feet, and has a chocolate-brown color quite similar to the soil of the Sharkey clay regions. These areas are more numerous in the lower portions of the prairie.

[1] U. S. Dept. Agr., Field Operations of the Bureau of Soils, 1901 and 1903.

Along the larger rivers, especially near their mouths, the alluvial belts of soil are quite wide. In these sections the rivers have laid down alluvium many feet in thickness on the older deposits. The building up of these flood plains has been very slow, and the marsh-grass growth has been continuous; thus we have near the top a muck with a high percentage of silt grading down into a silt with a large percentage of vegetable material at a depth of from 1 to 4 feet. Parts of this alluvial section are quite soft—almost semifluid—although the land immediately along the river channels is sometimes quite firm. The muck in these alluvial sections is quite similar to that of the Mississippi Delta section, except that the silt is well mixed with the muck instead of occurring in alternate layers.

CROPS.

The staple crops grown in this section of the State are sugar cane, rice, corn, forage crops, and truck. In certain parts, especially along the lower portion of the Mississippi and in other districts near the Gulf, large areas are planted in oranges and other citrus fruits. In the eastern or delta portion of the section sugar-cane is the most profitable general field crop, while in the western portion rice is grown almost as exclusively as is sugar-cane in the eastern part. In both sections some corn is grown, but not enough to supply the local demand; as a result, good prices are maintained. Of the adaptability of the type of soil called the Sharkey clay, the Bureau of Soils says:[1]

> The Sharkey clay was not especially adapted to cane and cotton and was no temptation to producers of these commodities, but the increased interest of late years in the production of rice has given a new value to this soil, and if the problem of drainage can be cheaply and successfully solved, the soil is admirably adapted to the production of this crop. Near New Orleans the reclaimed areas are devoted to the dairy business and to market gardening. The fertility of Sharkey clay is almost inexhaustible, and when well drained it is adapted to any crop which requires a fertile clay soil. The crops most profitably grown near New Orleans are onions, cabbage, eggplant, and tomatoes.

From observations on the various reclaimed districts it would appear that all crops grown on the older lands bordering the river can be successfully grown on the prairie lands, although there are some differences in the methods of cultivation. The lands just recently brought under cultivation are much more fertile than these older lands, and with intelligent farming should not require an application of fertilizer for a long term of years.

NATURAL DRAINAGE CONDITIONS.

The natural surface drainage of this section is away from the Mississippi River and larger bayous of sedimentation, directly into the Gulf by way of bayous of the tidal erosion type. However, numerous canals are being cut through the bayous of the first type from the low-lying swamp or prairie lands, thus aiding in the drainage. Water covers the surface of the undrained lands for the greater part of the year. This water comes from three different sources—direct precipitation, river overflow, and tidal overflow.

Overflow Due to Direct Precipitation.

The water to be removed from these lands comes mostly from direct precipitation, and it is with reference to the removal of this water that the nature and capacity of natural drainage channels will be discussed. Owing to the

[1] U. S. Dept. Agr., Field Operations of the Bureau of Soils, 1903, p. 452.

slight elevation of the land above sea level all of the streams are very sluggish in character. Their surface slopes are always very slight and are due entirely to the piling up of the water in the interior until sufficient head is created to force the water out to the Gulf. At times of high tide in the Gulf and small precipitation in the interior, the current is often reversed in many of the streams, and salt water then flows many miles inland. However, at such times the water in the channels is so low that the tide rarely causes a stage sufficient to flood any of the adjoining land. (This condition should not be confused with tidal overflow, which will be discussed later.) The fluctuation in water level, due to direct precipitation, in the various bayous and interior lakes is never very great and depends quite as much on the direction of the prevailing winds as on the amount of precipitation. Bayou La Fourche is one of the largest and longest natural drainage channels in this section, extending about 120 miles into the interior. A gauge has been maintained for more than three years at a point about 70 miles inland from the Gulf, and back 1 mile from the bayou on a short canal which connects with the general water level in the swamps. The extreme variation of the water surface observed at this gauge was 3.4 feet. At the time of the lowest gauging the salt water had reached this point, so that it was approximately sea level. This low stage was caused by a combination of the following conditions: A prolonged and record-breaking drought, only 1.12 inches of precipitation having fallen in the preceding two months; warm weather giving high evaporation; and northerly winds followed by southerly winds, which later caused a gradual rise by bringing in the salt water. This low stage was 1.3 feet below mean tide for this point. During the winter of 1911–12 the stage reached its greatest height for the three years beginning June, 1909. It was then 3.4 feet above low tide, which is approximately sea level, and 2.1 feet above mean tide. This high stage was caused by a combination of the following conditions: Heavy and continual precipitation, 9.7 inches having fallen in the preceding 40 days, cold weather and small evaporation, and continued southerly winds.

At points farther inland the fluctuation in water level is proportionately greater. The situation on Bayou La Fourche is mentioned because it is typical of all the long sluggish bayous that carry away the drainage water. Most of the interior watercourses are connected with each other by cross bayous and canals so that they are all somewhat similar in their action. The drainage areas are very poorly defined, and no doubt lap somewhat, as some of the connecting canals and bayous often reverse direction of currents, according to the stages of water in the various parts of the system; for this reason it is practically impossible to measure the run-off from these drainage areas. It is probable that the natural run-off is very low, due to small slopes and the rank vegetation on all the land, only about 10 per cent along the bayous being under cultivation. The bayous of sedimentation are quite free from growth of vegetation, many of them having a considerable boat traffic which tends to keep them cleared out and in good condition as drainage channels. Those of tidal erosion are apt to be overgrown with water hyacinths, but owing to their greater depth these are also quite efficient channels. As shown in figure 1, many parts of this section discharge their drainage water almost directly into the Gulf, or into large interior lakes that undergo very little fluctuation in water surface. Thus these areas are relieved of all drainage water due to direct precipitation without great rise of water in the carrying channels. In the interior portions, such as that contiguous to the upper part of Bayou La Fourche, there are often rises of water level of several feet in the main drain-

age channels. In this flat country a rise of 3 to 4 feet in the main drainage outlet is a very serious matter, and one that demands attention.

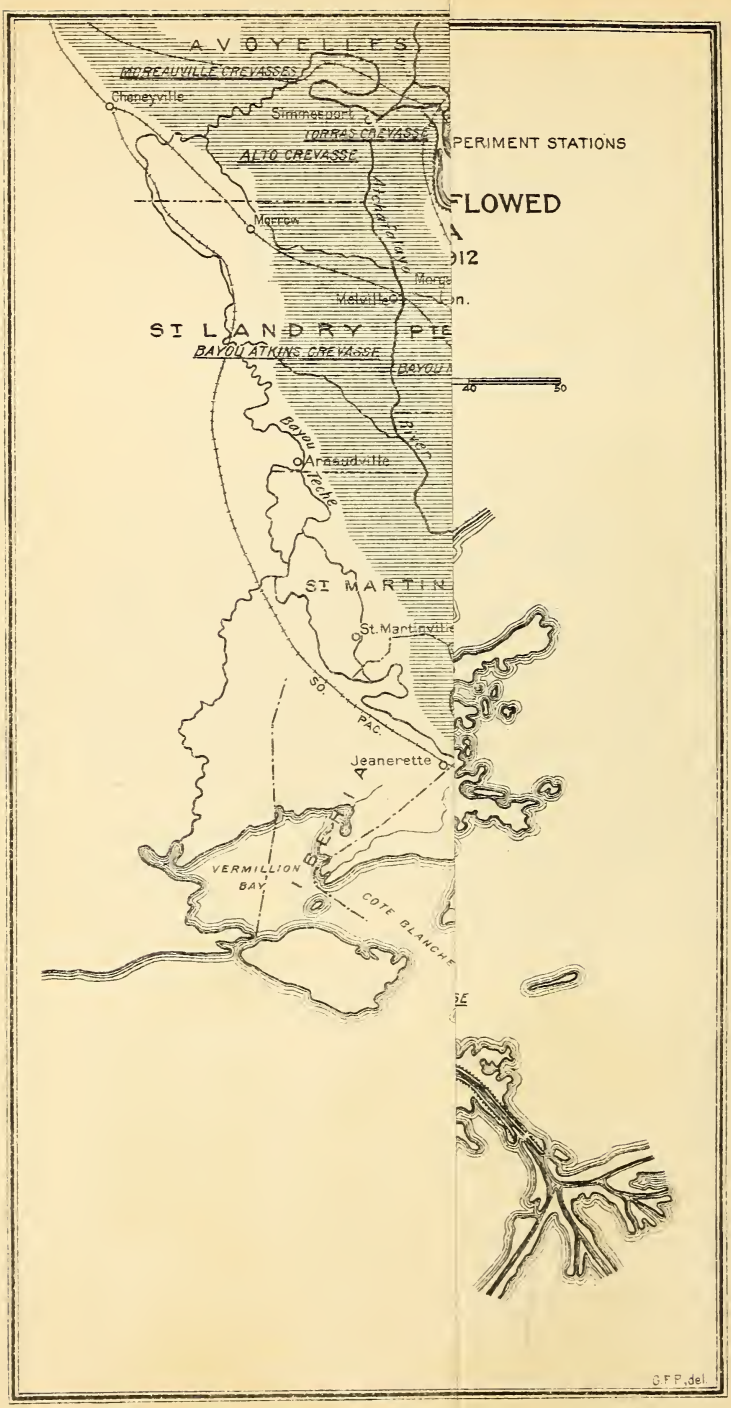
In reclaiming land in this section the usual practice is to inclose the district with levees to keep out the surrounding water; the drainage water of the land so inclosed is then pumped over the levee into some natural bayou that leads to the Gulf. If the fluctuation in water level in this outlet bayou is great, not only is a more expensive pumping plant equipment necessary, but the cost of the levees is very greatly increased. As the usual height of the levees is but from 3 to 5 feet above the ground level of the marsh, a rise of 3 to 4 feet in the outlet bayou will often endanger the levees or at least cause a considerable seepage through them. The danger from seepage is especially great because the fluctuation of the water level takes place very slowly. Thus in the vicinity of the tidal gauge in Bayou La Fourche, near Lockport, the water stood, during January, 1912, more than 1½ feet above mean tide. Districts in this vicinity that were exposed to this tide did a large amount of pumping to get relief from seepage water.

Up to the present time little attention has been given to the problem of the disposal of the drainage water after it is pumped over the levees. Some sections never will be compelled to give this matter consideration, owing to their favorable locations on or near the Gulf or some other large body of water. On the other hand, there are sections of wet prairie that are isolated from any large bodies of water by distances of from 20 to 75 miles along the shortest natural outlet channel. Thus far few of these districts have experienced any difficulty in getting outlets, for the surrounding limitless prairie is so little above sea level that the drainage water can immediately spread out, and thus causes no trouble. The percentage of land yet reclaimed is so very small that no effect on the carrying capacity of watercourses could yet be expected.

As the work of reclamation goes forward and district after district is reclaimed, until a considerable portion of the whole area is appropriated, the drainage water when pumped over the levees can not spread over the surrounding prairie, for the latter will be inclosed by the levees of adjoining districts. The water will then be forced to flow through long winding channels to the Gulf, this distance often being as great as 75 miles. This will mean that the water level on the outside of these interior districts must rise until sufficient head is created to cause a movement of the water to the Gulf, thus greatly increasing the cost of reclamation and rendering unsatisfactory much of the work that is now apparently finished.

In the planning of gravity drainage districts the common interests of adjacent districts in securing good outlet facilities have in all parts of the country long been recognized. Experience has shown cooperation between such districts to be necessary. As yet, most of the reclamation districts that secure drainage by pumping are independent of each other, and, as pointed out above, those which are fortunately situated will remain so. On the other hand, interior sections will eventually need better outlet facilities to the Gulf if the present policy of developing small independent districts is continued.

It is evident that the various districts should be so correlated that there will be no interference between the different interests. This makes necessary a general survey of this district, covering the topographic and hydrographic features. A survey of this scope would show the probable future necessity of increasing the present capacity of the natural drainage channels, or perhaps of providing additional outlet channels for some of the more isolated sections. It is quite likely that such additional channels could be used as commercial canals, thus making them doubly valuable. The section of the country lying between Bayous La Fourche and Terrebonne, in the parishes of the same names, is an



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excellent illustration of an area that eventually will need better outlet facilities, parts of this area discharging drainage water through 80 miles of natural drainage channel to reach the Gulf. As shown by the gauge at Lockport, the natural water surface in the swamps already has a large fluctuation, and any further extensive reclamation of land without improvement of the main drainage channels will doubtless considerably increase this fluctuation. A survey of this area would be needed to determine whether or not the present channel should be improved or whether any channels should be cut through the central portion of the district. Local landholders have suggested the possibility of combining such a main drainage outlet with a commercial canal to the Gulf, thus affording the district better transportation facilities. A thorough survey of the district would determine the feasibility of such a combination of interests.

River Overflow.

Like all delta regions this one was originally subject to periodic overflow. The smaller floods of the Mississippi River were confined within the natural levees that the stream itself has built up, but at irregular intervals of some years great floods would for months cover practically all of the delta. As soon as any serious attempt was made to bring this land under cultivation, levees were built along the Mississippi River banks to protect the lands from overflow. Districts were finally organized which included long stretches of river, and in all millions of dollars have been spent in levee improvements. This expenditure, with such Federal aid as has been available, has built a continuous levee system on both banks of the river throughout its length in the district under consideration. The levees have been increased in size as fast as the protected land could supply the money. In the earlier years, owing to insufficient cross section of levees and low grade line, crevasses were of frequent occurrence in times of high water. As more and more work was done on the levees a greater degree of protection was secured, until now crevasses and consequent overflow are very rare and occur only at times of record-breaking floods. The levee system is still far from complete. As illustrative of the flooding possibilities due to crevasses in the present system of levees, figure 3, published by courtesy of the Mississippi River Commission, shows the area overflowed during the record-breaking flood of 1912. It is evident that not only the reclamation of the swamp land but the successful cultivation of practically all of the higher land east of the Atchafalaya River is dependent upon the prevention of overflow of the Mississippi River. The interests involved in such overflow and the damage resulting are of such ever-increasing magnitude that there is every reason to believe that the work of completing these levees will be done in the immediate future. Prominent levee engineers who are acquainted with the problem believe that with the completion of the levee system this whole area will be protected from overflow of the Mississippi River. The above remarks apply to the alluvial section of the country, as very little land west of the Atchafalaya River is affected by Mississippi overflow. Some of the larger streams, such as the Calcasieu and the Sabine, flood the alluvial flats of land immediately along their banks to a depth of perhaps 4 feet, but as a whole the wet prairie lands of this western portion of the coast are free from river overflow.

Tidal Overflow.

The daily range of tide along this portion of the Gulf coast is quite small, the average being from 0.5 to 1.5 foot. However, as is true of all low, flat coasts bordering on wide areas of comparatively shallow water, heavy winds which

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blow for any considerable length of time directly on shore may cause a rise of several feet in the water. Such rises are commonly called storm tides. Their effect is so great that often they reverse the ordinary tide, and the maximum height of water may be reached at the usual time of low tide. Storms of this character usually occur during the months of August, September, and October, and are known as tropical hurricanes. Those that are severe enough to cause large rises in the tide occur at comparatively long and irregular intervals. Sometimes they will affect only a comparatively small portion of the coast line, while at other times a general rise of several feet will be recorded all along the coast line, with a limited region where the storm center strikes the coast experiencing a tide of perhaps twice the height of the general rise. One of the most characteristic as well as one of the most severe storms ever experienced in this section occurred September 20, 1909.[1] It produced high tides all along the coast and gave the maximum tide at the mouth of Bayou Terrebonne, about 40 miles west of New Orleans.

As it was apparent that this storm was very general in character and caused high tides all along the coast, Mr. A. M. Shaw, who at that time was carrying on investigations in this section for the Department of Agriculture, made special efforts to ascertain the maximum height reached by the tide, and for this purpose visited points all along the coast. The height of the tide was ascertained by the combined testimony of all reliable parties who were on the ground and by high-water marks on buildings. Only information from reliable sources was accepted. To quote from Mr. Shaw's report:

> The high-water marks obtained were fairly consistent, and were quite generally above any authentic high-water mark in the same locality.

Figure 1, page 2, shows the section under discussion, with the maximum heights of water above mean tide. With few exceptions this was the highest tide ever experienced on the coast, although more violent storms of limited extent have been recorded. Commenting on these high-water marks Mr. Shaw says:

> These may be considered authentic, excepting that the heavy seas that swept over the site of the camp at Sea Breeze made it impossible to get an accurate record at this point. The record shown of 15 feet may be in error 2 or 3 feet.

In regard to the extreme height at this point, he further says:

> An examination of the accompanying map will show that the mouth of Bayou Terrebonne lies between two large bays, and it is possible that this unusual rise may be accounted for, at least in part, by the sudden veering of the wind, thus concentrating the extreme tides of both bays on the central point. The foregoing report of the progress of the storm at New Orleans shows that such a sudden change in the direction of the wind did occur at that point and a similar decided change was described by a number of persons on both Bayous Terrebonne and La Fourche, all of the accounts agreeing that this change took place while the storm was at its worst.

An examination of the conditions at this point on the coast shows further reason for this extreme height of tide. The water in both Timbalier and Terrebonne Bays is comparatively shallow, ranging in depth from 4 to 12 feet. It has been the observation of the United States Coast and Geodetic Survey that where the water is shallow for a great distance offshore, heavy winds cause a flow of the entire depth of water, thus allowing no undertow. This action would give the water a tendency to pile up wherever it encountered an obstacle. This explanation is further supported by the fact that on more exposed portions of the coast, but where the water was deeper, the tide was not nearly so high.

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[1] For a minute description of this storm at New Orleans, see U. S. Dept. Agr., Monthly Weather Review, 1909, p. 623.

Thus on Timbalier Island, directly opposite the mouth of Terrebonne Bayou, the rise, according to the lighthouse keeper, was only 6 feet. At Port Eads, which is practically 12 miles out in the Gulf, and where the water is much deeper, the rise was only 3.4 feet and subsided in a few hours.

To the westward of this portion of the coast line the tides due to this storm were not nearly so high. This was doubtless due to the difference in the character of the coast line, and to a less intensity and duration of the storm. Concerning this section Mr. Shaw says:

> In the western portion of Terrebonne Parish, the flood height amounted to about 5 feet with a gradual falling off to the west. On the Big Wax and Little Wax Bayous and Bayou Sale, in St. Mary Parish, the maximum floods probably do not exceed 4 feet.

As mentioned in the general description of this section, the coast line of the western portion is very regular in outline, and immediately along the beach there is an almost continuous ridge of sandy material. The water directly offshore is deeper than that along the eastern coast, at least is deeper than the numerous lakes and bays of the eastern section, and as a result the tides due to wind have never reached the height experienced along the coast of the eastern part. The high tides have never overtopped these ridges, and as the water only poured in through the low places it did not enter in sufficient volume to flood the land deeply before the recession of the tide occurred. By closing these comparatively short gaps in this ridge, complete protection from tidal overflow would be secured for the western section, but some provision would necessarily have to be made for discharging the natural drainage water from the interior.

From an examination of figure 1 it would appear that reclamation districts on many portions of tne coast will be compelled to build levees not only to keep out the water of the surrounding swamps, but also to prevent tidal overflow in times of storm. The heights of the tide indicated on this map are the highest that have been experienced since the country has been settled, and should govern the height of levees on districts in the various localities. From a study of the nature of these tropical hurricanes the Weather Bureau forecaster at this point has concluded that there is an area of maximum velocity of wind in these storms that strike the coast, and that at or near where this maximum velocity occurs a much higher tide than the average may be expected. In the storm of September 20, 1909, the area of highest wind velocity struck the coast at or near the mouth of Bayou Terrebonne. As the storm center may strike at any point in future storms we may expect tides over limited areas exceeding those of the above-described storm, but it is unlikely that in general the present records will soon be exceeded. It is probable that these severe storm centers will occur on the Gulf coast with about the same frequency as do the tornadoes of the upper Mississippi Valley, and therefore it is suggested that protection from them should be sought in insurance rather than in building levees of sufficient height to prevent overflow from these limited areas of extremely high tide.

In connection with the problem of protection from tidal overflow, the plan of providing a general protection levee for the whole of the coast line, rather than of constructing individual levees for each district, has been considered by local engineers. The feasibility and cost of such a plan could be determined only after a complete survey of the district had been made, and a comprehensive plan had been carefully worked out. However, there are some general features that can be stated, thus giving an idea of the nature of the problem. The larger the levee district, other things being equal, the less the cost per acre for levee, for the length of levee per unit of area varies as 1 divided by the square

root of the area. Thus, if the cost for levees on a given district is $10 per acre, the charge on an area four times larger and of the same shape would be $5 per acre. Moreover, the doing of work along broad lines and the handling of earth work in large quantities would reduce somewhat the unit costs of construction. A levee location along the coast would have the advantage of a more or less continuous chain of islands, some of which are never overtopped by high tides, and many of which are nearly high enough at present to prevent overflow. That such a levee would not need to be as high, in order to keep out all tides, as one farther inland is proven by the high-water records of the storm of 1909, and those of earlier storms; this fact is also shown by the action of the natural levee along the coast of Vermillion and Calcasieu Parishes. By inclosing large natural depressions, such as bays and salt-water lakes, a considerable reservoir capacity could be secured by regulating the stage of water in them through the use of gates and locks in the levee. This would form basins into which the main drainage channels of the interior could discharge. A levee in such an exposed location must necessarily be capable of resisting the direct action of the waves, and steps would have to be taken to check the present cutting away by the Gulf currents of these natural levees. The oyster and fish industry of this portion of the coast would be greatly affected, as practically all of the oyster beds would be inclosed by such levees. However, if the proportion of salt water could be so regulated as to insure safety to the oyster beds the plan would be of benefit to the industry, as it would protect them from the damaging action of storms. The inclosing of such bodies of open water as Timbalier or Terrebonne Bays would not entirely eliminate storm tides in them; Lakes Ponchartrain and Maurepas, although well inclosed by the natural land surface, showed strong tidal action during the storm of 1909.

DESCRIPTION OF RECLAMATION DISTRICTS.

Previous to about 1907 there had been no active movement in the drainage of the wet prairie lands of Louisiana. The older plantations had extended their clearings back to the belt of cypress swamp that usually lies between the ridge along the Mississippi River and the grass-covered prairie; there, owing to the expense of clearing such land, further progress was usually checked. At some points, however, where this belt of timber was narrow, the plantations have been extended to include relatively small areas of prairie land. Such areas were inclosed with levees, ditches were cut, and pumping plants installed. The land thus reclaimed on such a small scale has proved to be very fertile and has been farmed with entire success. About 5 years ago the present movement for reclaiming large areas of wet prairie land began, and districts consisting entirely of wet prairie land were inclosed by levees and drainage systems installed. The degree of success attending these early reclamations interested people from many points outside as well as within the State, and at present the work is being prosecuted with an ever-increasing vigor. From the drainage engineer's standpoint the work has passed the experimental stage, and by following the best methods used on existing districts the successful drainage of the average type of wet prairie land seems assured. However, owing to the comparative newness of the work, many problems have yet to be satisfactorily worked out.

The degree of success attained in the various methods used in the reclamation of these lands has been quite closely investigated by this office. This investigation has included studies of the natural features of a number of drainage districts and of the levees, reservoir canals, field laterals, pumping plants, and methods of cultivation, as well as the records of rainfall and run-off. A large number of districts have been examined closely, and practically every district within the State has been inspected.

In order better to explain the nature of the drainage problems encountered and the reclamation methods employed, a detailed discussion of a number of reclaimed areas will be given, and a summary of the results of all investigations presented. The areas discussed are arbitrarily designated by numbers. These examinations were made or completed during the spring of 1912, and the descriptions refer to conditions at that time.

EXPLANATION OF TERMS.

Before proceeding with the discussion of the reclamation districts a brief explanation of some of the technical terms hereinafter used will be given.

By run-off is meant the water that flows over or through the ground to drainage outlets. All run-off originates in precipitation; therefore the latter is the most important of all the factors that influence the rate of run-off, some other controlling features being size, shape, topography, and geological structure of the watershed, climatic conditions, and the character of the vegetation.

In so-called gravity drainage districts the run-off is removed by gravity through the main outlets. In pumping districts the run-off is collected at some central point within the district and pumped over or through the levee. The rate of run-off is expressed as a quantity of water removed in a unit of time. This quantity of water can be conceived as a certain depth distributed uniformly over the entire drainage area. Similarly, the capacity of a pumping plant is the quantity of water, expressed in a depth uniformly distributed over the drainage area, that the pump can dispose of in a given time. As used in the following discussion, the rate of run-off is expressed by the depth of water, in inches, distributed uniformly over the drainage area, that passes from the area in a period of 24 hours. Likewise, pumping plant capacity is expressed in terms of a depth of water, uniformly distributed over the drainage area, that can be removed by the plant in 24 hours of continuous operation. Reservoir capacity also is represented by a uniform depth distributed over the drainage area. The object of expressing the rate of run-off and the pump and reservoir capacities in depths rather than in volumes per unit of time is to arrive at a basis of comparison that is independent of the drainage areas. On any particular tract, the area being known, these rates can of course easily be reduced to cubic feet per second or to any other convenient unit.

In a long period the total amount pumped would approximately equal the run-off for that period, but for short intervals, as, say, 24 hours, the run-off from an area might be much greater than the quantity pumped, the excess being stored in the reservoir for subsequent pumping.

AREA NO. 1, WAGGAMAN, JEFFERSON PARISH, LA.

As shown in figure 4, this plantation, containing 2,600 acres, fronts on the Mississippi River and extends back into the prairie swamp lands in the rear. It is a typical example of one of the old river-front plantations which have been extended to include a comparatively large area of wet prairie land. The tract of swamp land, which makes up one-third of the present area of the plantation, was included by the extension of the levees about 12 years ago. A pumping plant was installed, and cultivation has been continuous since that date. The area of prairie included was quite typical of those in this part of the State, and was covered with a scattering growth of small willows and the usual rank growth of prairie grass. Originally the muck was about 3 feet deep, although at present, after 12 years of cultivation and decay, it is well compacted and has subsided or shrunk until it now averages 2½ feet lower than it originally was. The total fall in the surface of the ground from the front

to the rear of the plantation is about 10 feet. Part of the land could doubtless be drained by gravity, but at present all of the water goes to the pumping plant. In February, 1911, 200 acres of land lying along the river front were added to this plantation.

Levees.

As part of this tract is above all possible high water due to direct precipitation or tidal overflow, it is only partially inclosed by levees. Starting where the ground is only about 5 feet above mean tide, a levee was built around the lower part to a height of nearly 7 feet above mean tide. The levees were built

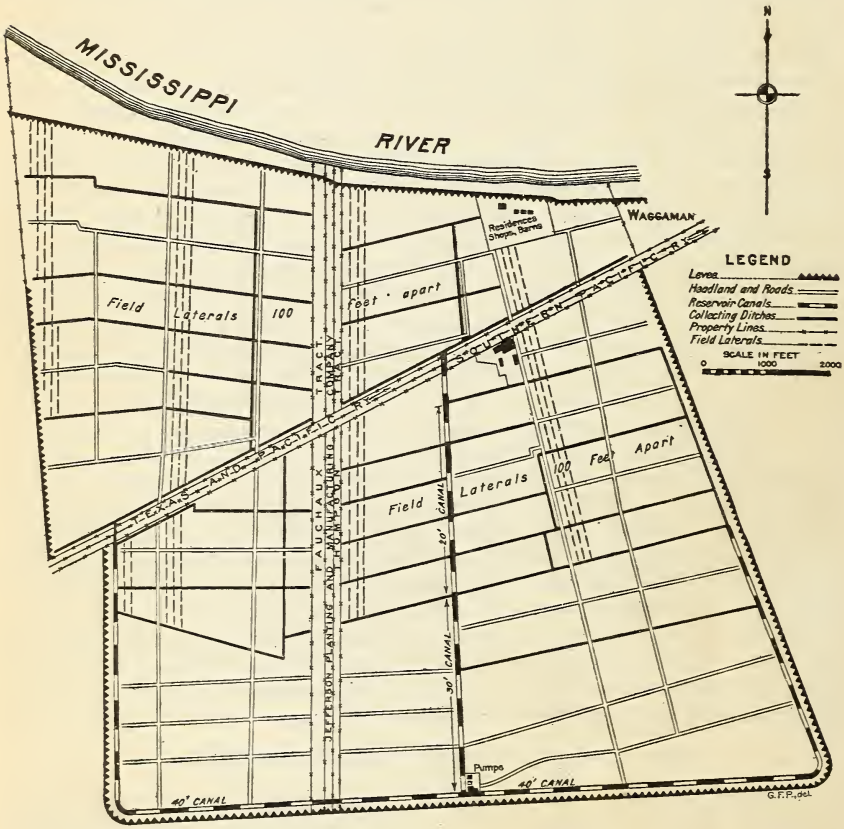


Fig. 4.—Sketch map of area No. 1, Waggaman, Jefferson Parish, La., showing ditch and levee system.

with a dipper dredge with material taken from the inside of the district. The canal resulting from the levee building was used for a reservoir. The ground was very soft and the levees were built up in several layers, but owing to the softness of the ground the excavated material formed a good bond with the foundation. The berm between the levee and the canal is now from 10 feet to 15 feet wide and is quite uniform. As they stand to-day, the levees seem to be almost impervious to seepage water. Nothing could be learned as to seepage during the first few years after construction, and they show no evidence of any sliding of material due to seepage. The levees have a top width of about 5 feet

and side slopes of 1½ to 1. The unusual height is accounted for by the fact that at the time of construction danger from high water, due to breaks in the Mississippi levees, was still great.

Reservoir Canals.

As indicated in the description of the levees, the reservoir canals on this district were cut with a dipper dredge. By using the canal so excavated as a reservoir, it was necessary to construct only a comparatively short canal into the interior of the district in order to give outlet to the collecting ditches. These ditches are mostly about 5 feet deep, with 10-foot top widths and 3-foot bottoms, and serve as outlets to the small lateral ditches.

Owing to an extensive silting up of the reservoir canals, their capacity is very much less than it originally was. During the whole time since their construction no attempt has been made to remove this deposit of silt. As a result the canals are not deep enough to afford outlet facilities to the ditches in the back lands. The pumping operations are also interfered with, in that the water is not brought to the pump rapidly enough to insure continuous operation at full capacity of plant during the removal of the run-off of a rain. This lack of reservoir capacity also makes the operation of the plant very unsatisfactory, as the water level must be kept nearly at the bottom of the canals to afford sufficient depth of drainage to the land. During the coming year it may be that the reservoirs will be cleared of silt with a dredge. This will allow opportunity to see what effect increased reservoir capacity will have on the pumping operations. Doubtless the greatest effect will be to decrease the number of days on which it will be necessary to operate the plant, although it is not likely that the total hours of operation or the amount pumped will be greatly affected.

Ditches.

The ditches on this plantation are of about the usual cross section, having depths of 3 feet, top widths of 3 feet, and bottom widths of 1½ feet. The average spacing varies with the character of the land. Thus, on the front lands which are rather impervious the spacing is about 100 feet, while on the back portion the ditches are from 300 to 500 feet apart. On the front lands the lengths of the laterals, between collecting ditches, are quite small considering the large slope of the surface of the land. Conditions on similar plantations where the ditches are twice as long indicate that the laterals of this district could safely have been made nearly twice as long as they are.

On the back lands, however, the ditches are already about as long as it would be advisable to have them, since the land is almost level and the reservoir canal quite shallow. At present these ditches are too shallow to give adequate drainage. Some measurements of the depth of water table were made during the early part of the summer of 1910. The results of these measurements are shown graphically in figure 5. It is apparent that as yet this soil is not very impervious, when compared to the lands of the vicinity of Bayou La Fourche and as shown by other similar measurements on area No. 2. (Figs. 8 and 8a, pp. 31 and 32.) Even after heavy rains the profile of ground water is not excessively steep. The ditches are spaced too far apart for the best results, although if they were of full depth they would very nearly drain the ground. It is the intention of the owners of this tract to deepen the present ditches to the usual depth of 3 feet and to construct new ditches midway between the present ones. The situation appears to be favorable to the placing of lines of tile instead of the new set of ditches. As the surface water is already handled by the present

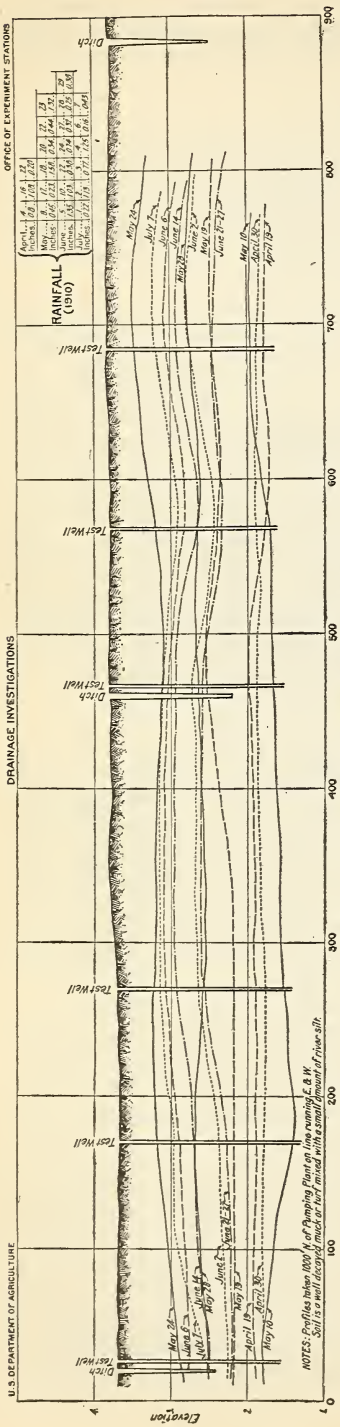


FIG. 5.—Profiles of ground water, area No. 1.

ditches the tile lines would need to remove only the ground water, and from the measurements of the ground water profile it would appear that they would easily fulfill this purpose. When the reservoir canal is deepened these lines of tile could be given sufficient fall to insure satisfactory operation. The cost of maintenance alone on these extra ditches would nearly pay the interest on the cost of the tile work above the cost of ditches; in addition, the saving in land would be considerable. Furthermore, if tile were properly laid they would give sufficient drainage all of the time, while ditches give their best results only for the first few weeks after they are cleared of grass and weeds.

PUMPING PLANT.

The location of this plant is quite favorable, as it is on the lowest ground in the tract and at the junction of three large canals, making the distance that the water must travel to reach the plant about as small as practicable.

Steam for the three following pumping units is furnished by two water-tube boilers and one return tubular boiler, crude oil for fuel and a feed-water heater being used.

First, a 40,000 gallon per minute maximum capacity rotary chamber-wheel pump, rope driven from a 16 by 24 inch automatic noncondensing engine; second, one 42 by 16 inch Menge pump, connected by a rope drive and a bevel gear to a 16 by 24 inch automatic noncondensing engine; third, one centrifugal pump with 36-inch diameter discharge pipe, direct-connected to a double vertical engine. Pumps 1 and 2 discharge into open flumes at an average head on pump of about 10 feet, which is about 5 feet greater than necessary. Pump 3 has a siphon on the discharge pipe, but the end is not always submerged.[1]

The capacity of this plant has usually been large enough to remove the water before any damage has resulted from flooding. Due to the rope drives. the plant has been stopped several times for repairs when the loss of a pump was a

[1] U. S. Dept. Agr., An. Rpt. Office Expt. Stas. 1909, p. 420.

serious matter. The heaviest rainfall that this plant has been called upon to handle since the records were begun occurred in the latter part of April, 1911, when 6.25 inches of rain fell in two days. The plant did not run at full capacity all of the time, so some flooding occurred for about 48 hours in the rear portion of the plantation; no large damage resulted from it, however. In view of the fact that this plant can not be depended upon always to run at full capacity, its present capacity is just about sufficient. There are a number of factors which make the run-off from this plantation greater in amount and intensity than it is from the average district of newly reclaimed wet prairie land. Among these are, first, a fall in the surface from front to rear of the tract of about 10 feet; second, a heavy and impervious soil on all the front lands, which comprise about half the entire area; third, a very complete system of ditches; fourth, complete and intensive cultivation; and fifth, a well-decayed and comparatively impervious prairie land in the rear portion of the tract. However, after the average district has been as long reclaimed as this district has been about the only one of the above factors that will differ, when it comes to making comparisons, will be the surface slope. It seems reasonable to suppose that the percentage of run-off on newly reclaimed districts will gradually increase until it is almost as large as it is on the tract under discussion.

The cost of operation of this plant in labor and fuel has been carefully kept, but due to inefficient machinery and large run-off from the front lands, it is considerably higher than where conditions are more nearly typical. Following is a summary of the cost of operation of the pumping plant on area No. 1 from June, 1909, to December, 1911, inclusive.

Cost of operating pumping plant on area No. 1, June, 1909, to December, 1911, inclusive.

Date.	Rainfall.	Run-off.	Cost.					
			Labor.	Fuel.	Total.	Per acre.	Per inch of water removed over tract.	Per acre-foot lifted 1 foot.[1]
	Inches.	*Inches.*						
1909 [2]	42.32	16.33	$600	$936	$1,536	$0.64	$94.00	$0.09
1910	43.08	11.58	500	616	1,196	.50	103.00	.10
1911	52.32	23.42	753	1,267	2,020	.77	101.00	.08

[1] Calculated on basis of 5 feet effective lift. Actual lift 10 feet.
[2] June to December only.

Condition of Land for Cultivation.

For two years after this tract of land was reclaimed it was cultivated with only such drainage as was afforded by the reservoir canals. At the end of this time lateral ditches were cut at a spacing of about 400 feet, and good drainage thus secured for a number of years. Not much detailed information was available concerning conditions during this early period. It is known, however, that during this time excellent crops were grown on this prairie land, and that they were uniformly better than those grown on the front lands. Up until the last two or three years the prairie lands were so much better drained than the front lands that plowing could be done on them when the water stood on the surface of the latter. As is shown by figure 5, the depth of drainage is now very small on these lands, hardly more than a foot. However, crops were reported as being

good, even with such shallow drainage. The manager said in this connection that although the crops were good the cane, especially, did not seem to stand drought very well. This probably was due to the very shallow depth of root growth that such a small depth of drainage would permit. As this tract is a part of the typical wet prairie found in this section, the results attained would seem to show that the successful reclamation of these lands already is a certainty.

AREA NO. 2, LOCKPORT, LA FOURCHE PARISH, LA.

This tract (fig. 6) adjoins the village of Lockport and contains 647 acres. The land from which this district was reclaimed is typical of the open grass-

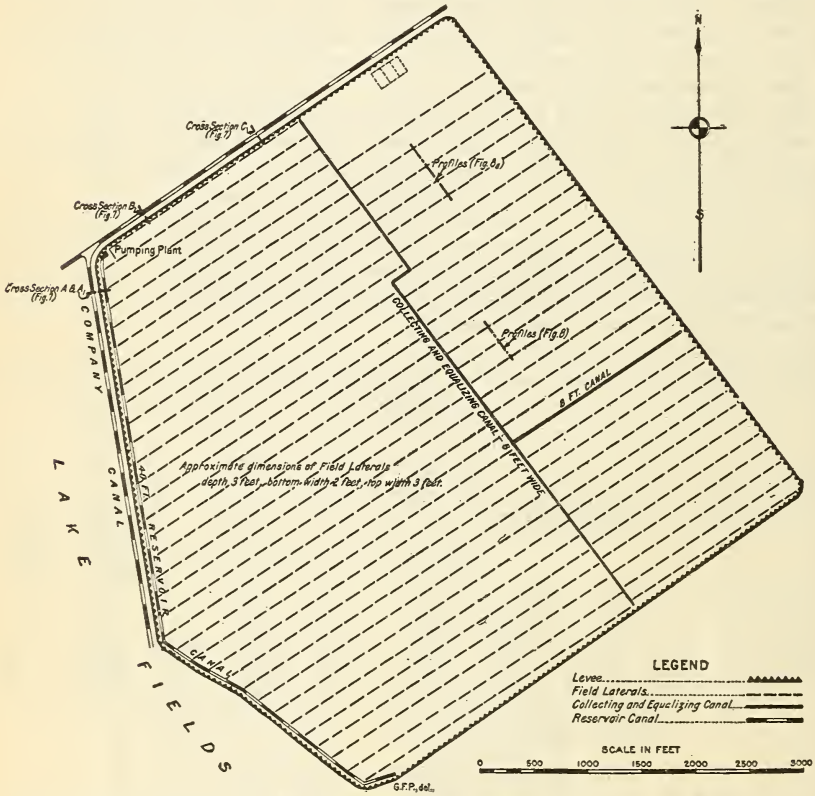


FIG. 6.—Sketch map of area No. 2, Lockport, La Fourche Parish, La., showing arrangement of ditches and levees.

covered prairies that lie to the west of Bayou La Fourche. The front levee line is located about 1 mile back from the bayou, and is nearly parallel to it. From here the tract extends back into Lake Fields, which at one time covered to a depth of from 1 to 3 feet about one-half of the area inclosed with levees. The muck on this tract varies in depth from 18 inches on the higher portions to perhaps 8 inches on the bed of the lake. A detailed description of the character of this muck has been given in connection with the special investigation of muck soils (p. 13). Reclamation on this tract was started in 1907, and the area was nearly all brought under cultivation by the growing season of 1911.

Levees.

The front or northeast levee on this tract is located on ground about 2 feet above average tide. As the storm tide in this place is only about 2.5 feet above mean tide, the front levee is very small, perhaps 2 feet high and having a bottom width of 5 feet. Along the outside of this levee is a small diversion ditch designed to carry the water draining from the higher land in front across to the commercial canal on the side of the tract. Owing to the small size of the levee and also to the fact that it was built by hand, considerable seepage water finds it way into the front part of the district. The trouble from this source is noticeable only when the tide stands about a foot above mean height for any great length of time. Along the other three sides of the tract it was necessary to construct a levee varying in height from 3 feet at the front to 6 feet at the back along Lake Fields. Along this portion the present crown of the levee is about 5 feet wide, with a bottom width of about 35 feet. This would give a side slope of about 2½ to 1.

The levee along the north and south sides not only is in good condition, but it seems to allow about the minimum amount of seepage during ordinary stages of outside water, although there is no berm between the levee and the outside canal. There is no lateral ditch on the inside[1] of the levee nearer than about 180 feet, so that the actual difference of the water levels inside and outside of the district is rarely greater than 4 feet, and usually about 3 feet. While the percentage of muck in this levee is small, there seems to be a rather continuous layer of muck in the base. At ordinary stages of water there is no great seepage through this layer of material, but during December, 1911, and January, 1912, when the tide level of the outside water was for nearly one month 1½ feet above mean level, the seepage was very noticeable, and the pumps were kept in operation a much longer time than when removing the run-off of rainfall only. This levee was built with a dipper dredge, and no muck ditch was cut in the base. It now appears that the falling earth did not penetrate the layer of muck and form a bond with the underlying silt. The seepage was so great on some parts of the levee during the above-mentioned period of high water that a ditch was cut along the middle of the levee for some 300 or 400 feet, and refilled with a dipper dredge. This method of refilling gave better results than that of hand filling and tamping, and rendered quite impervious the part of the levee so treated. The levee needs similar treatment for its entire length. The levee along the back or southwestern side of this district was built under conditions somewhat different from those attending the construction of the levees on the other three sides, this levee being located in the open water in the lake. The material placed in this levee was very soft, so that a number of layers were added before final completion. It was started in 1907, and the last addition was made in 1910. At first this levee was badly situated, as on the outside there was a canal having a depth of 6 feet, and immediately on the inside, with no berm between, was a reservoir canal with a depth of about 10 feet. The width of the levee at the level of the outside water was 35 feet, and more or less seepage occurred when the lake stood above its usual level for any length of time. At such times the head of water on the levee frequently was 7 or 8 feet. This seepage seemed to take place through defective spots in the body of the levee rather than through the base, for it was only when the water was above mean height for a considerable time that

[1] The side of a levee on which the protected land lies is termed the "inside."

seepage occurred. At ordinary stages of water the levee is hard and dry, although the base always is submerged. However, the condition of the levee was so unsatisfactory that during the latter months of 1911 a new reservoir canal was cut parallel to and about 40 feet distant from the old one, and the old canal was filled and considerable material deposited along the inside slope of the levee. This improvement should greatly reduce the seepage.

Experience on this tract seems to show that it is not good practice to place the reservoir canal immediately inside of the levee, especially if the base of the latter be below ordinary water level. Figure 7 shows cross sections of these levees, the stages of water in the canals, and the curve of the ground water through the levees at various times. It is apparent that there is considerable advantage in allowing a liberal cross section for such levees.

Reservoir Canals.

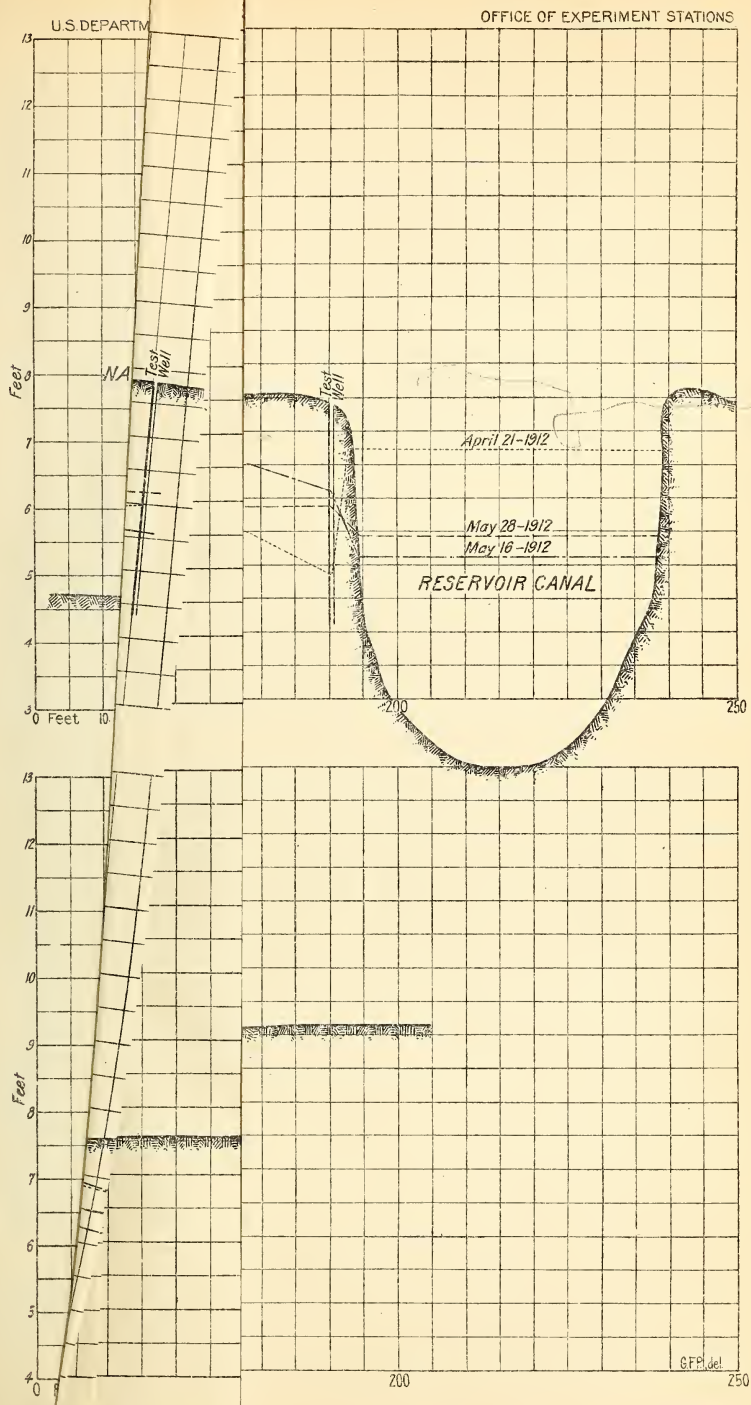
As this tract has a slope from front to rear of nearly 4 feet, the location of the reservoir at the lowest end of it was perhaps the best that could have been made to act as an outlet to the laterals. Originally it was about 35 feet wide and 5 feet deep. The storage capacity at this time was about 0.35 inch of water over an area of 647 acres. During the growing season of 1909 and the winter of 1910 it became partially filled with silt. In the spring of 1910 a 6-inch hydraulic dredge was employed to pump out this silt. The dredge did not work satisfactorily, but finally succeeded in taking out sufficient material to give the reservoir its former capacity. However, with a pumping capacity of about 1.1 inches in depth over the whole area in 24 hours the cross section of the canal was not large enough. After the water was lowered at the pump to the bottom of the canal it was still about 2 feet deep at the farthest part of the canal, a distance of 1.3 miles. It was then necessary to shut down the pump for perhaps 5 hours, after which an additional run of about 2 hours would take the water that had collected during the interval.

As above mentioned, this canal was reexcavated in 1911, and now has a depth of 8 feet and a width of 40 feet. The capacity is 0.45 inch in depth of water over the entire area. Even before the reservoir was reexcavated the combined capacity of the pumping plant and reservoir was sufficient to keep the land from flooding except for a few hours at times of extreme storm. With the larger canal the pumping plant is operated continuously until practically all of the water is removed.

Ditches.

Due to the fall of about 4 feet to the mile in the surface of this tract it was considered feasible to extend the lateral ditches the full length, 1 mile. The ditches are of about the usual cross section—i. e., top width 4 feet, bottom width 1.5 feet, and depth 3 feet. They are spaced uniformly 160 feet apart. This seems to be a satisfactory arrangement, as the ditches have always given good drainage and have never been flooded for any great length of time. A length of 1 mile does not appear to be too great for ditches of this cross section and fall. In this case each of these ditches is draining about 25 acres of land, or carrying off 1.5 cubic feet per second on a basis of 1.5 inches run-off per 24 hours.

The cost of maintenance on these ditches is no small item. It is necessary to cut the weeds out of them at least twice each year and it is sometimes done three times. Once in two years it is necessary to take out about 1 cubic foot of material per linear foot. On this basis the annual cost of maintenance is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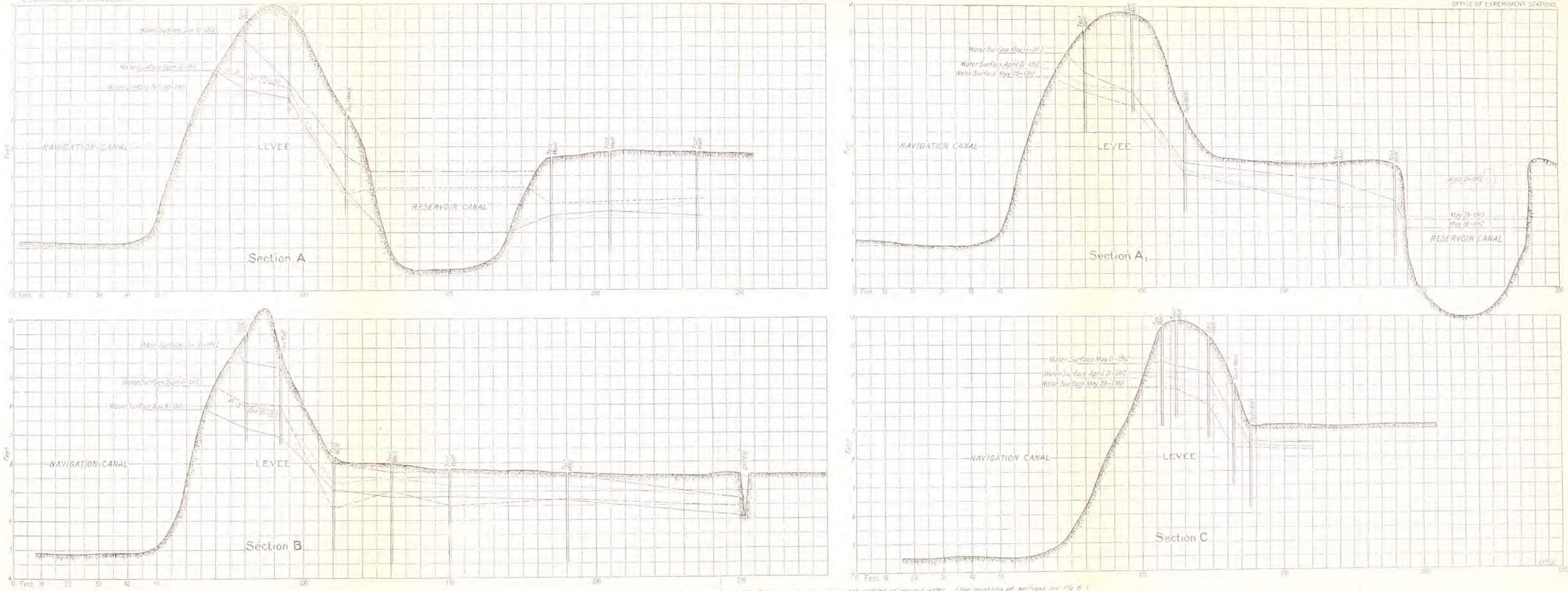


Fig. 7.—Cross sections of levees on Area No. 2, showing water stages and profiles of ground water. (For locations of sections, see Fig. 6.)

about $0.75 per "acre"[1] of ditch. With the present spacing of 160 feet the annual cost of ditch maintenance per acre of area drained is about $1.

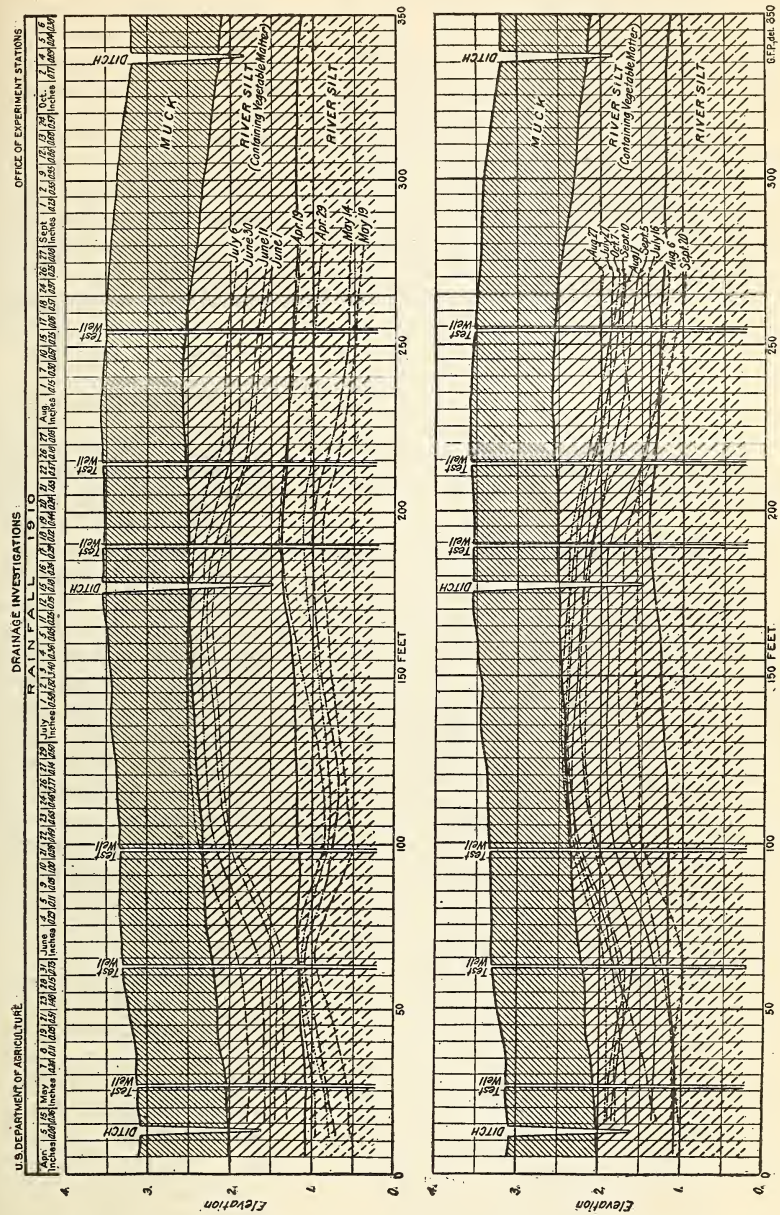


Fig. 8.—Profiles of ground water on interior of area No. 2.

During the summer of 1910 some measurements of the depth of the water table below the surface were made. The results of these measurements are shown graphically in figures 8 and 8a. It is evident that after long and heavy

[1] The term "acre" is in common use in the section under discussion as a unit of length in rough land measurements. Its value is the length of one side of a square whose area is 1 acre, or about 209 feet.

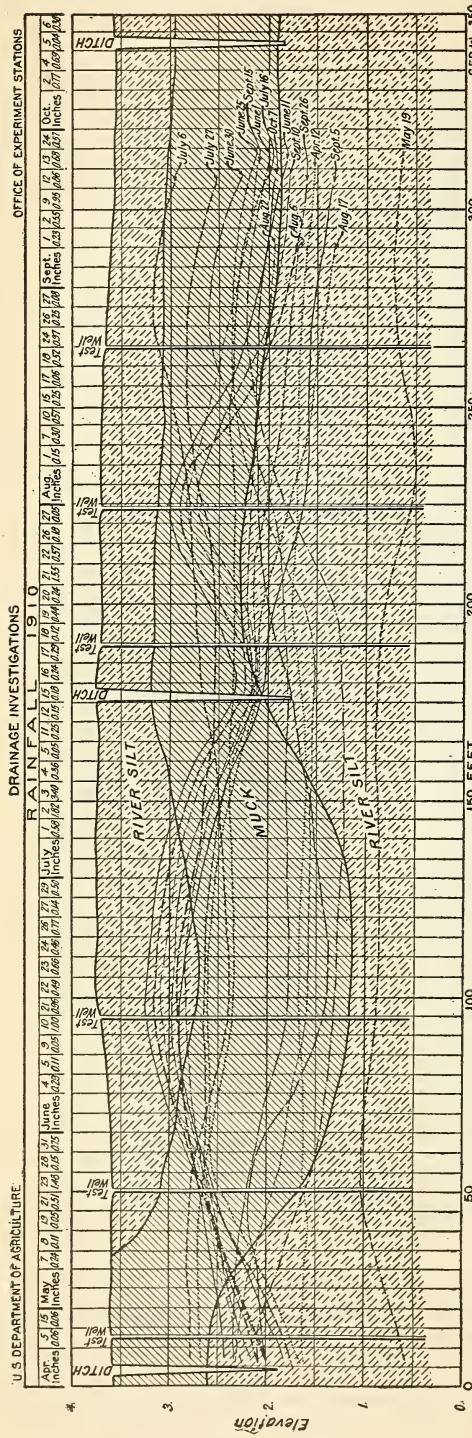


FIG. 8a.—Profiles of ground water on interior of area No. 2.

rains the ground water profile is quite steep, but that it rapidly flattens out. Although the silt on this tract is very fine grained and impervious, there is evidence of considerable lateral movement of the water through it. It was considered by the landowner that the depth of drainage was sufficient for the growth of crops. Corn was the crop on the ground at the time these measurements were taken.

PUMPING PLANT.

The plant is located at one end of the reservoir canal (see fig. 6, p. 28) and discharges by a short wooden flume directly into the commercial canal outside. There are two vertical centrifugal pumps of the square wooden-case type, with impellers 32 by 12 inches and 24 by 8 inches, respectively. Each pump is rope driven by a slide-valve noncondensing engine, steam being supplied by a 100-horsepower return-tubular boiler. A feed-water heater has been installed within the last two years.

As far as mere capacity is concerned, when running continuously, this plant is satisfactory. However, as regards reliability and efficiency, as well as cost of upkeep and operation, it is far from being an ideal plant. The chief trouble lies in the type of pump. The wooden-case pump with its rope drive is constantly giving more or less trouble; the expense for extra labor to repair the rope drive

added to the cost of new rope is a considerable item. The loss of power in the rope drive is unavoidable and the loss of the use of the pump at a critical time due to the breaking of a rope is a serious matter. This pump while adapted to a low lift is not suitable for a varying one. The total lift, to be on the safe side, must be about 1 foot above ordinary high tide, and when the variation of the tide is 2.5 feet with the effective lift only 4.5 feet, as it is in this case, it is apparent that the actual lift of the pump is often nearly twice the effective lift. Again, being made almost entirely of wood, repairs to this style of pump are frequently necessary, and as the parts to be repaired are usually under water the pump must be detached from the foundation and raised before the work can be done. These pumps while low in first cost are very short lived when compared to the cast-iron centrifugal type. Thus, considering the greater rate for depreciation and repairs on this style of pump as compared to the cast-iron centrifugal form, it appears that the latter might be preferable on this score alone.

A reliable pump if placed in this plant could be of considerable less capacity than the present ones and still be of ample size. The heaviest rainfall since the records of pumping have been kept occurred in July, 1910, when 5.58 inches fell in 2 days. A reliable pump with a capacity of 0.75 inch per 24 hours would have taken this water out rapidly enough to have prevented a longer flooding than 12 hours.

Condition of Land for Cultivation.

During the growing season of 1909 the front one-third of this tract was practically the only part that was sufficiently well drained to admit of cultivation. These front lands naturally were a little firmer than the portion that originally was a part of Lake Fields. The back portion was fairly well drained for two years previous to the season of 1909, but the land had not become firm enough to allow its cultivation with animal-drawn machinery. The drying out of these muck lands is accompanied by the formation of large cracks that extend to the soft mud below, and it is only after these cracks have been closed that cultivation can be done in the ordinary manner. The lateral ditches were all well cleaned and the silt was removed from the reservoir during the early spring of 1910. Although the spring of 1910 was unusually dry, all of the lake bed was not solid enough to be cultivated. Early in the spring of 1911 all this land was plowed with a gang of six turning plows drawn by a gasoline traction engine mounted on the apron traction instead of wheels. Corn was planted in this land and it was cultivated in the usual manner, since the one thorough plowing had completely filled the holes and cracks. The period necessary to bring the land under complete cultivation was about four years. This period could have been shortened if the drainage had been complete and continuous from the first and the land plowed a year sooner with a traction engine. Corn seems to be the easiest and best crop to grow on these new lands, followed by sugarcane the second and third years. Excellent yields of all kinds of truck have been grown on this plantation. Cane produces especially well and the tonnage per acre is very much greater than on the older lands along the bayou, exceeding their average nearly 50 per cent. No special treatment was given this soil when bringing it under cultivation and it does not appear that any was necessary.

AREA NO. 3, LA FOURCHE PARISH, LA.

This district (fig. 9) lies about 5 miles south of the village of Raceland and borders on the upper end of Lake Fields, this being the same lake from which a part of area No. 2 was taken. The district contains 940 acres. The surface

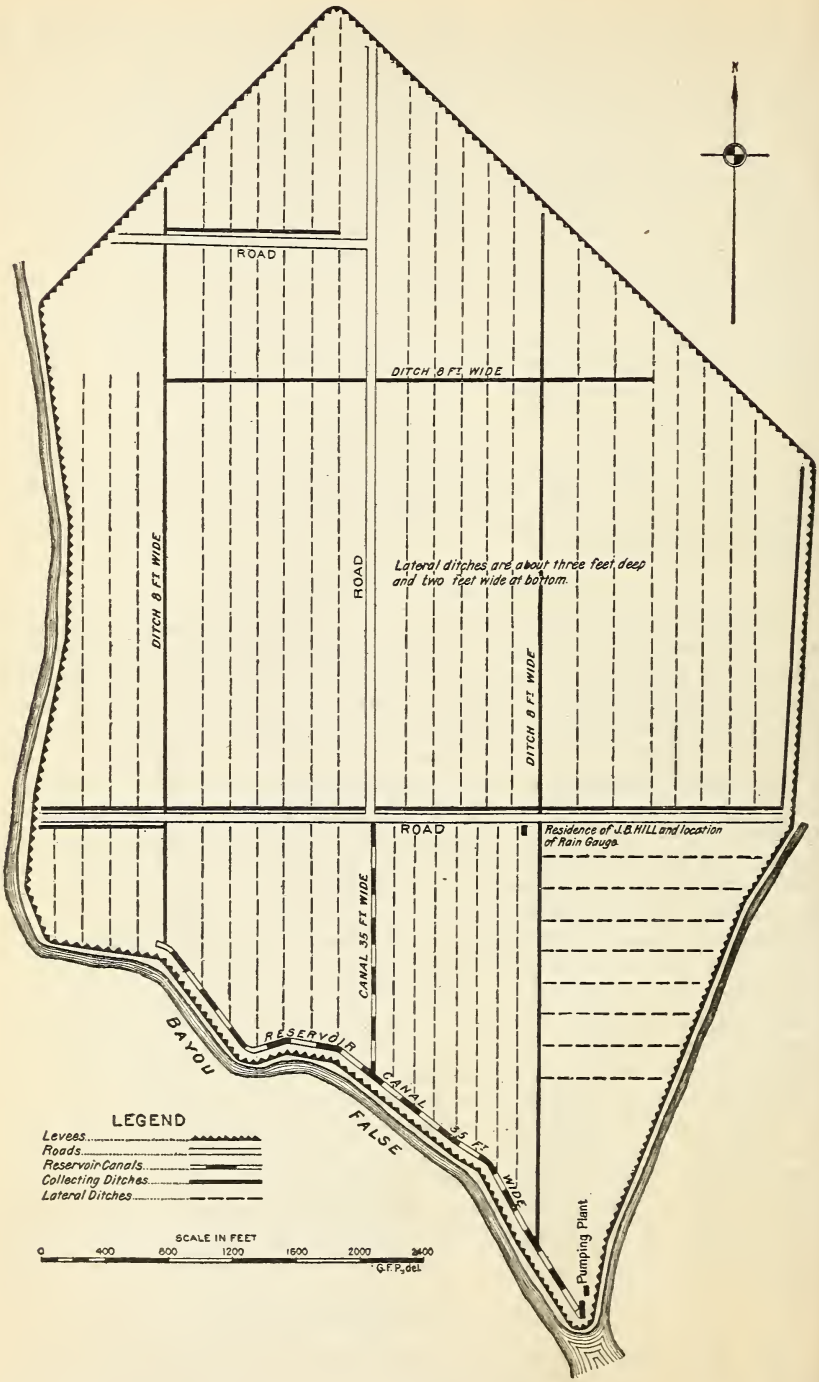


FIG. 9.—Sketch map of area No. 3, near Raceland, La Fourche Parish, La., showing ditch and levee system.

slopes gradually from a height of about 3 feet above mean tide at the north end to lake level at the south. Reclamation on this tract was started in 1907, and the first extensive cultivation was done in 1909. The condition and general character of the muck has previously been described in the discussion of muck soils. (See p. 12.)

Levees.

For the most part the levee was built of material taken from the outside of the district. The work was done with a dipper dredge with a short boom, and the berm on the outside is very small and in some places entirely lacking. The levee was gone over two or three times before it was brought to its present height of 4 feet above mean tide. The present crown is about 4 feet wide and the side slopes are nearly as steep as 2 to 1. When this levee was built no muck ditch was made in the base nor was any of the surface cleared of vegetation. The levee was cut by a trench some months after it had been built. This showed that the material, when placed, did not force its way through the muck and form a bond with the underlying silt. At this point the muck was quite turfy in character, but not more so than the average muck of this part of the prairie. The layer of muck under the levee was considerably compressed, but it certainly was still quite pervious when compared to silt. The fact that the base of this levee is above ordinary outside water level probably accounts for the fact that no great amount of seepage appears. In the lower and softer part of the district some of the material in the levee was taken from the reservoir canal. Here a berm of from 10 to 15 feet was left between the levee and the canal, the muck being so soft that the mud, when dropped from the dipper, undoubtedly cut through the muck to the silt below. The same condition existed here as gave trouble on area No. 2, except that there was a berm on the inside of this levee and the difference in the level of the water inside and outside was never as great as on area No. 2. If the reservoir had been of sufficient depth to drain thoroughly the lowest land in this district, the head of the water against the levee might have been great enough to cause a noticeable amount of seepage. During the fall of 1911 the reservoir was deepened about 3 feet and the material placed on the levee. As the levee has had a chance to harden for several years since it was first built, it is not expected that this increased depth of drainage will cause a greater amount of seepage through it. In this case no damage seems to have resulted from placing the reservoir canal close to the levee and from using the material excavated from it for levee building.

During the unusually high stage of water in this lake in December, 1911, and January, 1912, the levees on the higher part of the district leaked very badly, as might have been expected from a previous examination of the unbroken layer of muck in the base. In the softer portions of the district no great trouble was experienced from seepage. During the early months of 1912 a continuous muck ditch was cut along the toe of the inside slope of these levees and this refilled with material taken by an orange-peel bucket dredge from the bottom of the outside canal. The levees should now be in much better condition to resist seepage.

Reservoir Canals.

When this reservoir was first excavated the ground was very soft; as a result a deep layer of mud was soon deposited in the bottom. Owing to the fact that it was located in the lowest part of the tract it served as an outlet to the lateral ditches, but never was of sufficient capacity to aid in reducing the

required capacity of the pumping plant. The surface of the ground for a considerable distance around the pumping plant is much lower than that of the remainder of the district, so that the water was allowed to overflow the reservoir and to fill this low area. As no attempt was being made to cultivate this low area it was used in this manner for additional reservoir capacity. If an attempt had been made to reclaim the entire district the reservoir must have been found too small for any practical use, but by allowing this low part of the tract to be flooded the remainder was given fairly good drainage until the summer of 1911. The need of a better reservoir then became apparent and during the month of October the reservoir was excavated to a depth of 7 feet and a width of 35 feet. In addition to cleaning out the old canal a new portion was cut into the central part of the district. The capacity of the new reservoir above a 4-foot level is 0.25 inch; the reservoir should maintain this capacity, as the surrounding ground is quite firm. In excavating along the old reservoir the material was found to be solid enough for each dipperful partially to hold its shape after being dropped on the spoil bank. Considerable difficulty was encountered, however, in removing the soft mud that had collected in the bottom of the reservoir. A hydraulic dredge would have been much more satisfactory for taking out this mud.

Ditches.

During the first two years of cultivation on this tract lateral ditches of a depth of 3 feet, spaced as far apart as 600 feet, gave ample drainage. Due to the short length of reservoir canal it was necessary to construct some large collecting ditches to keep the lengths of laterals from being too great. These collecting ditches were about 8 feet wide and 4 feet deep, but as they were frequently nearly dry a strong growth of vegetation soon reduced their effective size very greatly. They did not afford the small lateral ditches sufficient outlet and consequently the tract was not well drained; at the same time the ground was becoming more impervious, due to the decay of the muck. Lateral ditches were then placed about 200 feet apart and the ditches were cleaned out. During the summer of 1911, one of unusual precipitation, it was found that about halfway between adjacent lateral ditches the ground was saturated with water to the surface. Some of the landowners now propose to place lateral ditches as close together as 100 feet. It would seem that this is as yet unnecessary. In the first place, the laterals were not at that time of the usual depth of 3 feet; they were not kept in good condition, and some of them were nearly three-fourths of a mile long, and furthermore the reservoir canal was not of sufficient depth to keep the water out of these ditches. If the above defects were remedied, it certainly would improve conditions greatly and might make the cutting of additional ditches unnecessary. The use of a collecting ditch instead of frequent reservoir canals, while it reduces the first cost of the drainage channels is rather unsatisfactory. The collecting ditch soon becomes grown full of weeds and grass, while a small reservoir canal will always have water in it and will not so easily become obstructed. Plate I, figure 1, shows an apron-traction ditcher cutting laterals on this district.

Pumping Plant.

The plant is located in the lowest part of the district. The pumps discharge through a short wooden flume into the lake. There are two 32 by 12 inch vertical centrifugal pumps of the square wooden-case type. One of them is belt driven and the other rope driven, each by a 12 by 16 inch slide-valve noncon-

densing engine. Steam is furnished by two 60-horsepower locomotive type boilers. The machinery is on a timber foundation, supported on piling, and the building is a frame structure covered with heavy corrugated galvanized iron. In type the plant is very similar to the one on area No. 2 and is subject to the same general criticisms. In capacity it has always been sufficient, but due to the small reservoir it could only be operated at full capacity for rather short periods. However, the new and large reservoir remedied this difficulty, although on account of its length the collecting ditch will always bring in the water rather slowly.

The present conditions are favorable to a small percentage and a low intensity of run-off. As the district is more completely brought under cultivation, however, and the water is more promptly pumped out, both the amount and the intensity of the run-off should increase, although it is not likely that this will be large enough to require an increase of the present large pumping capacity. In August, 1911, this plant burned; it was reconstructed, the present plant being a duplicate of the former one. In a plant of this character, where most of the structure is of wood, the danger of fire is much greater than in the more recent type of pumping plant. These latter are equipped with cast-iron centrifugal pumps mounted on concrete foundations and are built with some idea of making them fireproof.

Condition of Land for Cultivation.

In bringing this land under cultivation the first crop was planted on the higher portions after a year of drainage. Before the muck became decayed it drained very readily, and, as stated on page 36, few laterals were necessary. Good crops of corn were grown on this land with the water table only 1 foot below the surface. Sugar cane has also successfully been grown on this land, as have all kinds of truck. No special treatment has been given the land before cultivation. Not all of this district has been cultivated, though it is now all solid enough to be easily cultivated if the water were kept sufficiently low. This tract could have been brought under cultivation much sooner if it had been well drained the year around, instead of only during the growing season. In draining new land it is important to keep it well drained all of the time, so that the soft mud will have a chance to harden.

AREA NO. 4, RACELAND, LA FOURCHE PARISH, LA.

This district, containing 2,400 acres, is similar in natural conditions, such as soil and elevation, to area No. 3, and borders it along one side. While in size it is more advantageous than any of the districts heretofore mentioned, its shape, due to natural boundaries, is not as good. However, the various details of reclamation have been somewhat better carried out in this district than in those previously discussed. The map of area No. 4 is shown in figure 10.

Levees.

Most of the levee was built by a dipper dredge with material taken from the channels which the map shows outside the protected area. No ditch was cut in the base of the levee nor was any other preliminary work done. Along Bayou False the levee was built from material taken from both inside and outside the district. This bayou had been opened for navigation several years before the levee along this district was built. The spoil bank had settled until it was quite firm, so that the material taken from the reservoir canal, when deposited on this firm base, formed a levee of sufficient cross section the first time over

with the dredge. Along most of the boundary of the tract the ground was so solid that once over with the dredge, cutting a 35-foot by 6-foot canal, gave more than enough material to build a levee. The average height of the levee is 4 feet above mean tide, and the top width, while variable, averages about 5 feet. All of the levee has not been brought to an even grade as yet, and much

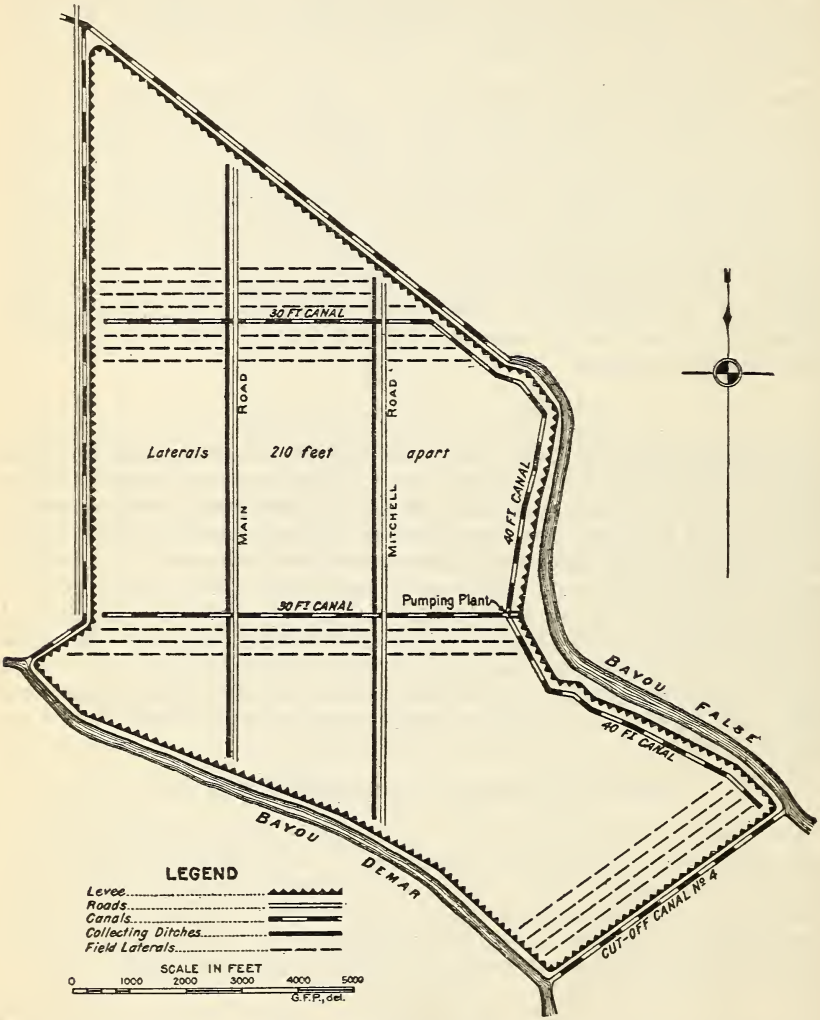


FIG. 10.—Sketch map of area No. 4, Raceland, La Fourche Parish, La., outlining arrangement of ditches and levees.

of it has been allowed to grow up in weeds. As far as can be noticed, this levee is practically free from any great amount of seepage at ordinary water level. For the most part the base is above mean tide, and no doubt this fact partly accounts for the good condition of the levee. Where the reservoir canal parallels Bayou False a 10 to 15 foot berm was left along both sides of the levee, making the total distance between canals nearly 60 feet. On the other portions

of the tract the berm along the outside of the levee is smaller and averages about 5 feet in width. As ditches do not parallel this levee except on one side, and then not closely, the small width of berm should not prove a serious defect as far as seepage is concerned.

As stated on page 37, no muck ditch was cut in the base of the levee, and at ordinary stages of water no large seepage was apparent. However, during the high water that affected area No. 3 the levee leaked badly, and, as was the case in area No. 3, the water seemed to come through the base where the layer of muck occurred, rather than through the body of the levee itself. This defect was remedied by cutting a ditch along the slope of the levee and filling it with material dredged from the bottom of the canal. This not only cut off seepage through the base of the levee, but added somewhat to the cross-sectional area.

Reservoir Canals.

Owing to the size of this tract it was necessary to cut reservoir canals into the interior to give outlet to the system of laterals. This rather extensive length of canals gives a larger reservoir capacity than is had in any of the other districts of this vicinity. Between the surface and a distance of 4 feet below these canals have a capacity of 0.40 inch of water over the entire area. It is possible for the pumping plant to lower the water below this level, but under ordinary circumstances this is approximately the level to which the water is reduced. The added depth of reservoir (the canals are nearly all over 6 feet deep) will be of service in reducing the velocity of flow in the canals during the time of pumping and also in keeping their bottoms covered with water. This last feature will in a measure prevent the growth of weeds and grass and the consequent choking of the canals. In December, 1911, these canals were quite badly filled with a deposit of soft mud, 2 and even 3 feet having been deposited in places since the cutting of the canals some two years previous. This deposit is quite rapid during the first year of drainage. It is due partly to the wash from the laterals, but also to the crumbling and the sliding of the sides of the canals. The sliding is especially great when water is lowered too rapidly when the district is first pumped out. By taking the water out very gradually it has been found that, even when the canals have been cut in very soft material, any great amount of sliding of canal banks can be avoided. In the softest portions of the prairie it has been found that there is a tendency for the surrounding mud to flow toward the canals when the water is lowered for the first time; the walls of the canals may continue to be even and unbroken, but the canals do not remain as wide nor as deep as they were before the water was lowered and this flow began. The material on this tract was too solid for any considerable amount of flow to be apparent. During the early part of the month of December, 1911, an 8-inch hydraulic dredge was started in these canals to remove this deposit of mud. It was found desirable on the larger canals to replace the hydraulic dredge with an orange-peel-bucket dredge. By cutting into the harder underlying material it was possible to remove most of the soft mud from the bottom of the canal. This redredging of interior canals seems to become necessary from two to four years after they are first cut.

The reservoir has thus far given satisfaction in the reclamation of this tract. The increase of lift during the operation of the pumps, due to the slope of the water surface, is quite small. The greatest length of canal tributary to the pumping plant is about 2¼ miles. The greatest length of drainage channel that the water travels is nearly 3 miles.

Ditches.

In this district, as in area No. 3, the collecting ditches have been used in connection with the lateral ditches to drain the ground. The collecting ditches have been placed along the roads and this has made it less difficult to keep them in good condition and also to see when they were in need of cleaning. However, these collecting ditches have not been easy to maintain, and it has been necessary to clean them out a number of times. It was the plan at first to place the laterals every 210 feet, but later they were placed at twice that distance. When the ground was first drained this greater distance was not found to be too great. In 1912, after two years of drainage and cultivation, a distance of 210 feet is considered by the landowners to be about as great as is safe. The laterals were at first 3 feet deep. This depth is not considered sufficient when the spacing between the laterals is as much as 210 feet. At times of heavy rains it has been found that the land between the ditches became too wet for best growth of crops.

Most of the laterals on this tract carry drainage water for at least 2,000 feet. This length seems to be allowable if the ditch is kept in fairly good condition. When ditches longer than a half mile are used, they must be increased in width and depth at the lower end, unless they are kept in perfect condition all of the time. On the lower and softer portion of this tract, unless some further collecting ditches are cut, the length of lateral will be nearly a mile; in view of the fact that this ground is almost level it is likely that this length will be too great. The percentage of land consumed in ditches and canals on this tract is quite small, considering the large area in reservoir. When all of the ditches are spaced 210 feet apart the area of land so consumed will be a little more than 2½ per cent.

Pumping Plant.

The pumping plant is quite well located to draw water from all parts of the district. The discharge is into Bayou False, which is about 60 feet wide at this point and so affords an excellent outlet. As this plant is of much better construction than any of the others of this group, a somewhat detailed description of it will be given (see fig. 11). The block of concrete which forms the foundation for the pumps and engines is about 17 feet wide and 50 feet long, and was placed approximately on the center of the levee with its greatest length parallel to the levee. This block is 8 feet thick and so extends below the plane of permanent water level, thus protecting from decay the piling that supports it. Around this foundation was driven a double row of sheet piling, and at each end a double row was extended some 15 feet into the levee. The sides of the intake basin also were protected by a double row of sheet piling, supported by a timber frame bolted to a number of round piles. The short length of discharge canal necessary to reach to the bayou was protected in a similar manner. Across the front of the intake basin a wooden screen prevents any floating matter of size from entering the pumps. The base of the pumps is set at about extreme low water in the bayou, and to protect the foundation from being flooded the concrete is raised in a wall about a foot thick along the outside to a height of 3 feet above mean tide. The whole of the foundation is well reinforced with steel, and the round piling under the concrete extends into it about 2 feet, thus insuring a perfect bond.

One 30-inch cast-iron centrifugal pump was installed in March, 1910, and a duplicate unit was added July, 1912. The arrangement and size of piping of the first unit is shown in figure 11. The important features are the enlarging and tapering of the pipes at the intake and discharge ends, the freedom from bends or elbows, and the horizontal cutting of the intake end of the pipe, the

latter feature permitting the water to be lowered to the end of the pipe without allowing the entrance of air. The saving in velocity head losses secured by enlarging the pipes amounts to nearly 2 feet, which is about one-half the usual lift. The pipes are supported by steel hangers secured to pairs of round piling. The pump is driven by a 14 by 16 inch vertical slide-valve engine, direct connected to the pump shaft with flexible coupling. This style of engine occupies less floor space and also requires shorter lengths of pipes on the pumps than does the horizontal type. In addition, it is less likely to cause vibration or motion of the foundation when operated at high speed. Steam is furnished by a return tubular boiler burning crude oil. The building for this machinery has a timber frame covered with heavy corrugated galvanized iron. The theoretical capacity of the completed plant, when both pumps are working

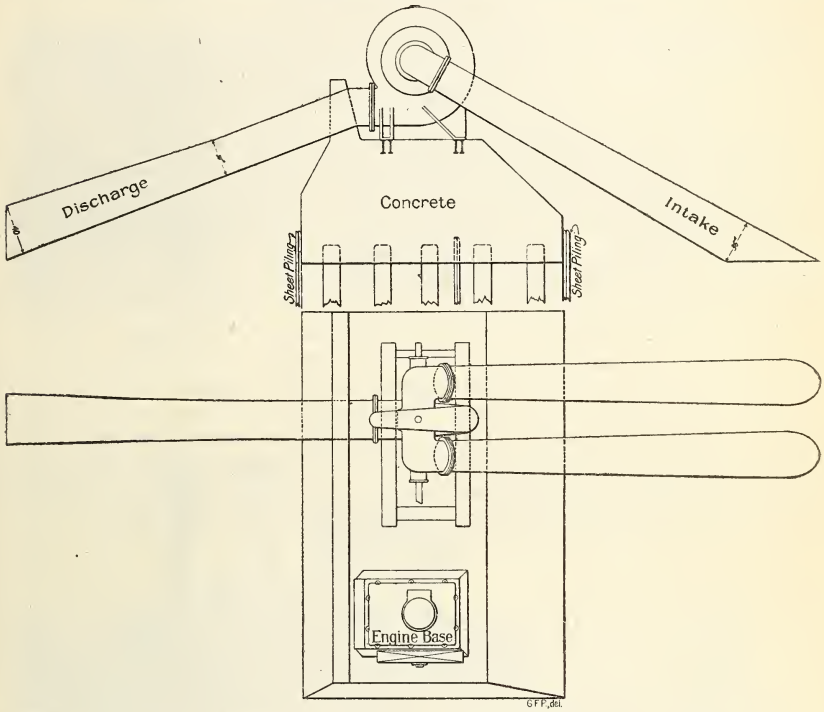


FIG. 11.—Sketch plan and elevation of one unit in pumping plant of area No. 4, Raceland, La.

most economically, will be 1 inch per day with a maximum of 1.4 inches per day. One pump, with a capacity of 0.7 inch per day, successfully drained this tract for nearly two years until the time of high water in December, 1911, and January, 1912, when, owing to the seepage through the levee in addition to the rainfall, the ground was flooded for two or three days. At this time the reliability of this plant was shown, as the pump was operated continuously for six days and nights. With the second unit installed, no trouble should be experienced in removing any rainfall encountered, especially since the levees are now much better able to keep out seepage. It is quite certain that when all of the tract is under cultivation and all lateral ditches are in operation the intensity and amount of the run-off will be largely increased, but, due to the large reservoir capacity of the plant, no trouble should be encountered.

Condition of Land for Cultivation.

The pump was first started on this tract about March, 1910. The canals had been cut some months before and the lateral ditches had also been in operation on the higher portions for about the same length of time. Some 300 acres of land were brought under cultivation during the spring of 1910, a large part of it by the use of horses and ordinary farm machinery. The remainder of this 300-acre tract was broken with a pulverizer attached to an apron-traction-ditcher frame. During the season of 1911 about as much more area was brought under cultivation. Nearly all of the tract that had been ditched could have been cultivated from the first. Much of the land in the lower portion of the tract is not yet completely ditched; in this part the ground is still far too soft to allow the use of horses or mules and ordinary farm machinery.

The general crop grown was corn, with a small acreage of cane planted in 1911. Both crops were uniformly good, the cane being especially heavy.

AREA NO. 5, DES ALLEMANDS, LAFOURCHE PARISH, LA.

This tract of land (fig. 12) is one of the newest of the reclamation districts, and has only been under drainage since September, 1911. It lies on the western side of Bayou des Allemands, which at this point is several hundred feet wide and from 10 to 15 feet deep. The district contains 1,880 acres and includes a portion of the village of Des Allemands, lying on the western side of the bayou and south of the Southern Pacific Railroad. The land is 1 or 2 feet above ordinary tidewater in the bayou, and a large percentage of it is made up of firm silt ridges, with a very thin layer of muck on the surface. At intervals there occur old muck-filled bayous, having widths of from 100 to 200 feet and depths of from 10 to 15 feet; however, the land is mostly quite firm, the proportion of such soft ground being about 10 per cent. Some of it was solid enough to plow in the ordinary manner as soon as the water was removed by the pumps. Except for a few scattering trees on the high ridges, most of the tract is covered with a heavy growth of the natural prairie grass. The muck averages from 8 to 12 inches in depth and is quite turfy in character.

Levees.

On two sides of this tract the problem of levee building was a simple one. The embankment of the Southern Pacific Railroad makes an excellent levee on one entire side and on the side that borders the bayou the solid ridge of silt was almost continuous and averaged about 2 feet above mean tide. Twice over with the dredge along the bayou made a levee about 5 feet high and having a top width of from 8 to 12 feet. The side slopes on this part of the levee are about 1½ to 1. It is expected to use this part of the levee for a road, and as the material is almost pure silt it should make an excellent roadway. After the first layer of material was placed in this levee a muck ditch was cut along its inside slope. When the second layer was placed this ditch was filled with pure silt taken from the bottom of the levee canal. This should give a levee that will be free from any great amount of seepage through the base. On the other two sides of the district canals had been cut some years before and the material thrown on both sides. This left a low solid base for the levee, and in most places once over with the dredge gave a levee 3 or 4 feet high with a top width of from 4 to 6 feet. The side slopes on this portion of the levee are from 2 to 3 horizontal to 1 vertical. The berm varies from 5 to 10 feet. Except where some old muck-filled bayous are crossed, the levee is high enough to pre-

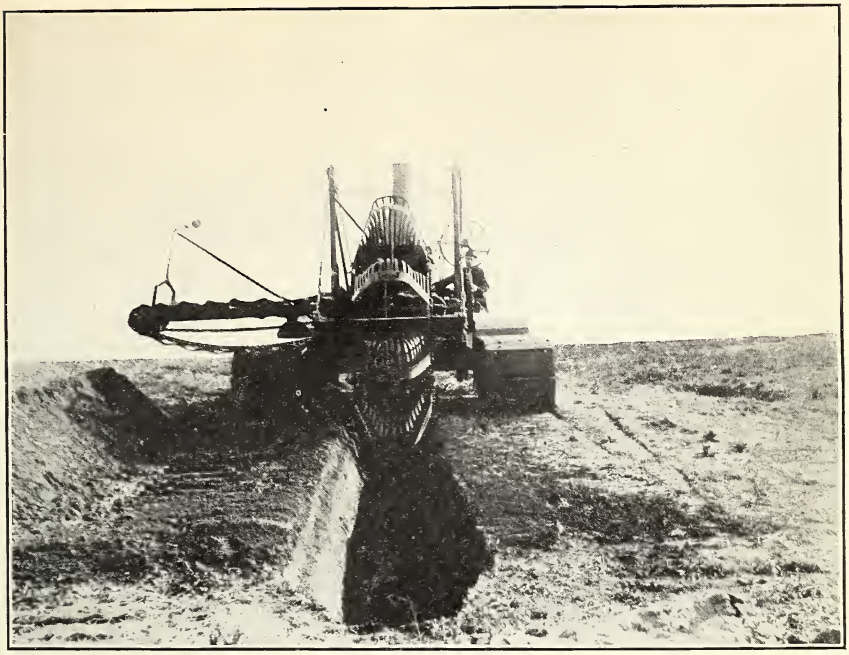


FIG. 1.—APRON-TRACTION DITCHER CUTTING LATERAL DITCH ON AREA NO. 3, RACELAND, LA.

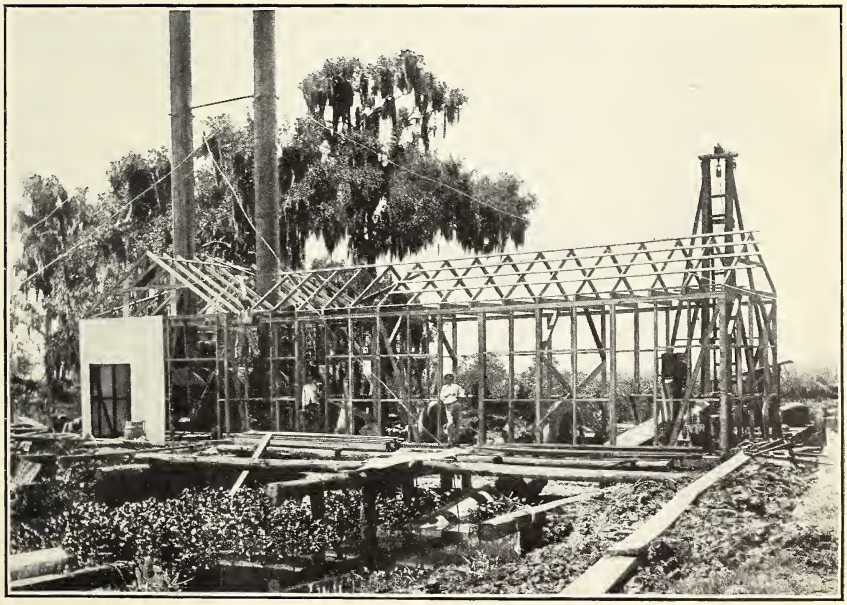


FIG. 2.—PUMPING PLANT (UNDER CONSTRUCTION) ON AREA NO. 5, DES ALLEMANDS, LA.

FIG. 1.—VIEW OF WET PRAIRIE BEFORE RECLAMATION.

FIG. 2.—APRON TRACTOR PULLING GANG OF BREAKING PLOWS AFTER RECLAMATION, AREA NO. 7, GUEYDAN, LA.

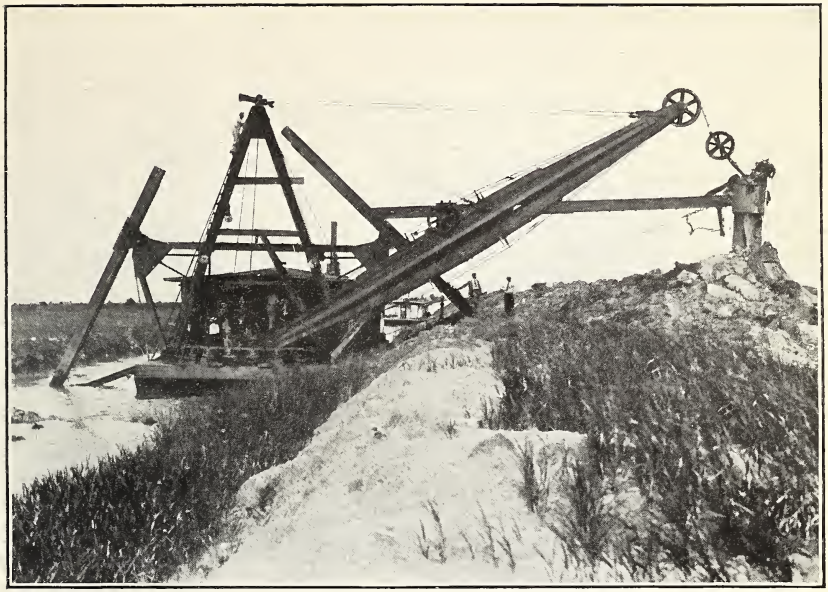


FIG. 1.—DIPPER DREDGE CUTTING 50 BY 10 FOOT RESERVOIR CANAL AND BUILDING LEVEE.

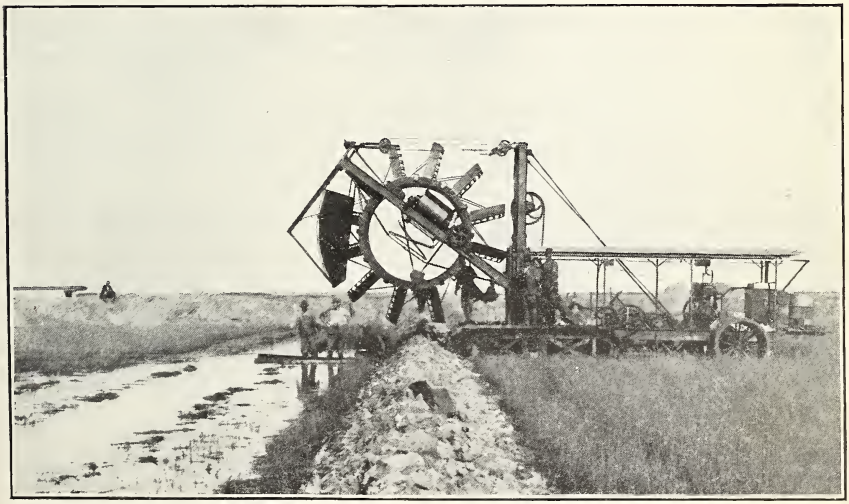
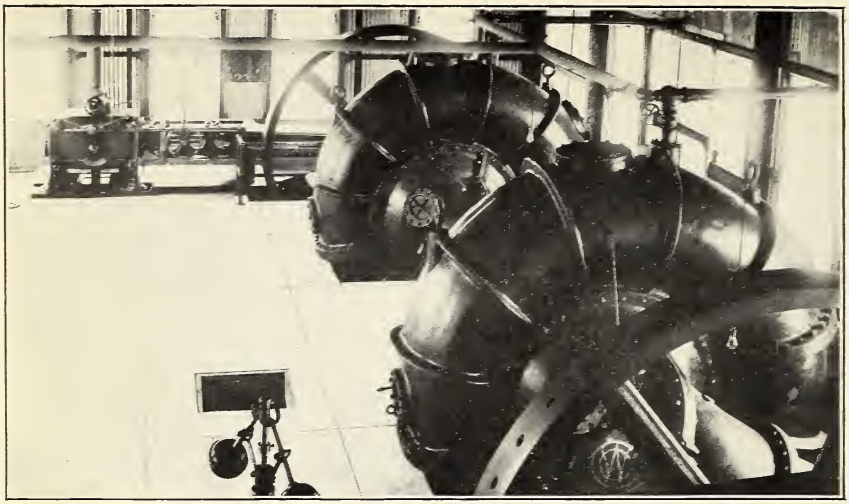
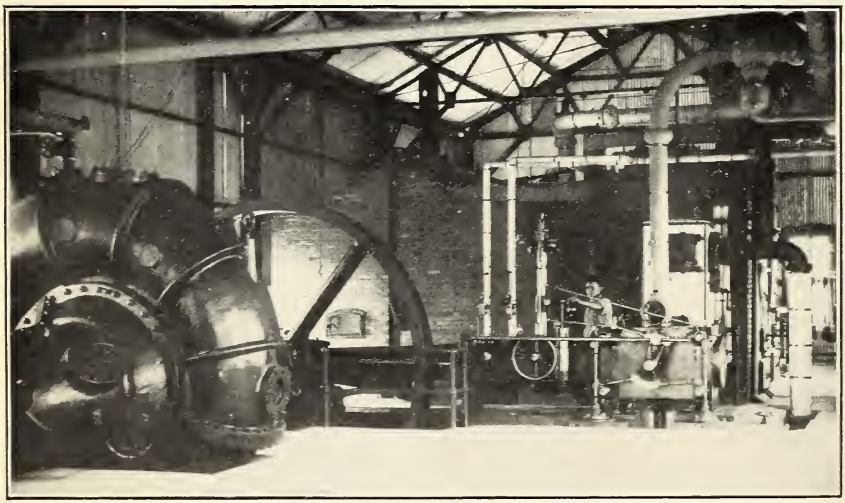


FIG. 2.—APRON-TRACTION DITCHER CUTTING LATERAL DITCH, AREA NO. 7, GUEYDAN, LA.





INTERIOR VIEWS OF PUMPING PLANT ON AREA NO. 7, GUEYDAN, LA., SHOWING ARRANGEMENT OF ENGINES AND PUMPS.

vent flooding. In these soft spots the levee is only about a foot above mean tide and considerable work will have to be done to bring it to grade. Additions are being made to these portions with hand labor, and at present subsidence has practically ceased.

On a portion of the levee where the old bank was used for a foundation some peculiar seepage conditions have become apparent. Water appeared in the interior of the district some 20 to 40 feet from the levee, and an examination showed that the subsoil of the impervious Sharkey clay was filled with holes that varied in size from that of the usual crawfish hole, about 1 inch in diameter, up to several inches, the latter probably being muskrat holes. This was in a place where the underlying subsoil was very solid. It will be necessary to cut a deep muck ditch along this levee and fill it with puddled earth.

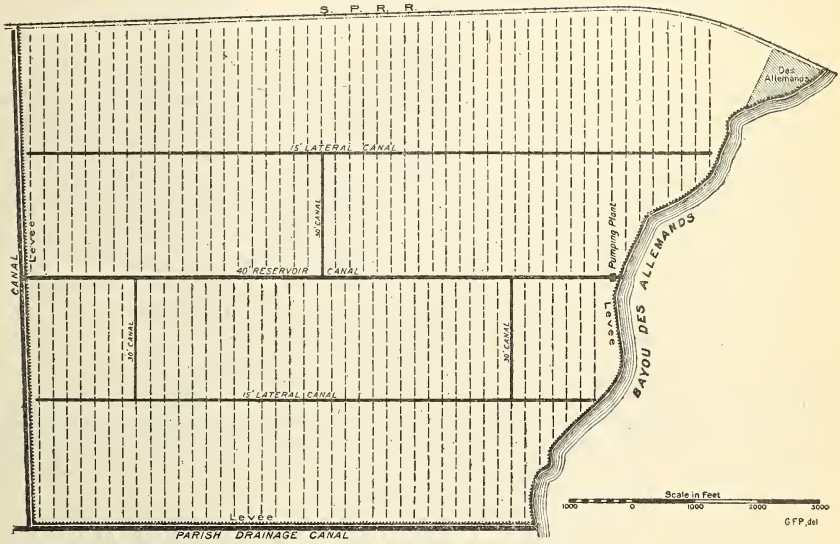


FIG. 12.—Sketch map of area No. 5, Des Allemands, La Fourche Parish, La., showing arrangement of levee and ditches.

RESERVOIR CANALS.

As shown in figure 12, the reservoir canals were all cut in the interior of the district. By extending the canals to all parts of the tract the necessity of small collecting ditches was eliminated. A small canal gives much better outlet to the laterals than a collecting ditch and is easier to maintain in good condition. These canals were cut with a dipper dredge and the material was deposited rather close to the sides of the canal. This resulted in a small amount of shrinkage in the size of the canals, there having been, in February, 1912, about 4 feet of soft mud in the bottom of each of them; part of this was perhaps left by the dipper dredge when cutting the canal. It was expected that an attempt would soon be made to remove this mud with a small hydraulic dredge; this should be a very favorable situation for its use. At the time of the examination the cross section of the main canal was so far reduced that the pumping plant could not be operated at full capacity after the water was

reduced to about 3 feet below the surface. The water was lowered very slowly in the canals, beginning about the 1st of September, 1911. No large slides occurred until about the end of December. At that time the water was lowered to the bottom of the canal and the banks became very soft, due to heavy and continued rains. In the immediate vicinity of the pumping plant, where the water was the lowest, and where an old muck-filled bayou was crossed, both sides of the main canal caved in for a length of about 200 feet. The surrounding ground surface for a distance of 100 feet was lowered by this action. The foregoing is a good illustration of the way this material will flow when conditions are favorable. The capacity of the reservoir system when it is brought back to its original size will be about 0.5 inch between the surface and a 4-foot level. This should bring the water to the pumps in sufficient quantities to keep both of them in operation until the water in the canal is lowered to at least a 4-foot level.

Ditches.

The spacing of ditches on this tract probably will be about 200 feet. It is likely that on the higher and more solid portions the ditches will not require such close spacing as this, at least for the present. The ditches were being cut with a ditcher similar to those usually employed on land of this character and will be of the usual size. They will discharge into the small canals and none of them will connect directly with the main reservoir canal. The idea is to cause the silt to deposit in the small canals and thus leave the large canal free from mud. Owing to the regular shape of the district and the regular arrangement of the canals the ditches will all be of about the same length and the whole tract should receive about the same degree of drainage. The length of ditch will be nearly 2,000 feet. With the good outlet that the canals will afford, when compared with collecting ditches, this length should not prove to be too long to afford good drainage. If the ditches are placed at the usual spacing of about 200 feet the proportion of land in ditches and canals will be 3.6 per cent.

Pumping Plant.

The pumping plant is located about 300 feet back from the bayou front, on a leveed outfall canal. The plant was thus located in order that advantage might be taken of a firm ridge of silt as a foundation for the machinery. The arrangement and character of the foundation are shown in figure 13 and are very similar to those of the foundation under the plant on area No. 4. In this plant there are two units, which are duplicates. The pumps are cast-iron centrifugal with a 24-inch diameter of discharge. Plate I, figure 2, shows this plant under construction and gives an idea of the arrangement of boilers and machinery. The discharge and intake pipes are both enlarged and tapered the full length. The area of the intake pipe is about four and one-half times and the area of the end of the discharge pipe is nearly three times that of the discharge opening on the pump. This enlargement saves a loss of velocity head of nearly 4 feet, which is about equal to the ordinary actual lift of the pumps. The intake pipes have but the one elbow where they enter the pump and the discharge pipes are both straight. These pumps should operate very efficiently, as everything possible has been done to cut out unnecessary losses. To each pump a 12 by 12 inch simple vertical engine is direct connected with a flexible connection. Steam is furnished by two return-tube boilers burning coal. Oil burners are now being installed. This plant has been in operation since September, 1912, and is running very smoothly. Both of the units have been run continuously for a period

of 4 or 5 days and were in good condition at the end of the run. This type of plant seems to give the reliability that is necessary in a drainage plant. Its theoretical capacity when operating at full load is 0.95 inch of depth in 24 hours.

AREA NO. 6, NEAR POYDRAS, ST. BERNARD PARISH, LA.

This district is part of a tract of 85,000 acres of land that lies to the south of the little town of Poydras, in St. Bernard Parish, being about 15 miles from New Orleans. The front boundary of the tract is for the most part the back line of the river-front plantations and the land extends back several miles. Most of the area is open grass-covered prairie, with only a narrow belt of timber near the front line. As a whole it is almost at mean tide level, the average elevation being not far from 0.5 foot. The muck is close to 4 feet deep and is not quite so turfy in character as is that in the vicinity of Race-

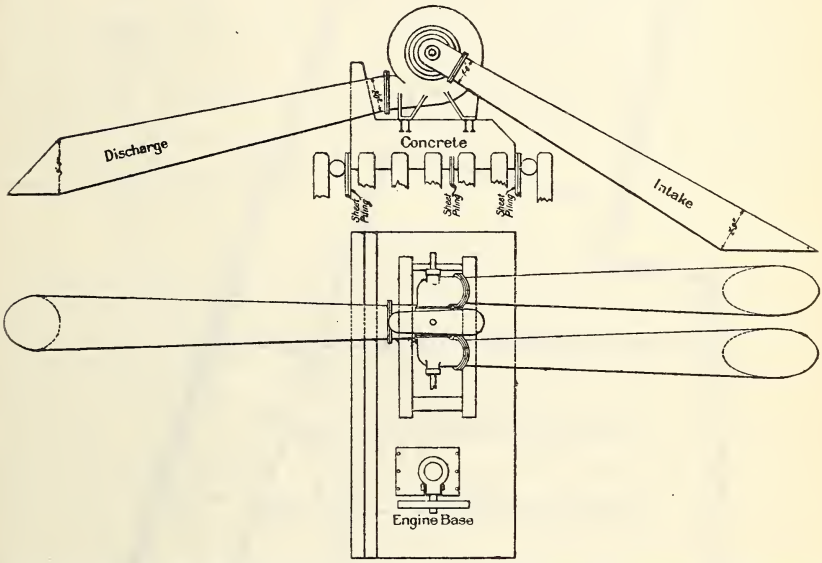


FIG. 13.—Sketch plan and elevation of one unit in pumping plant on area No. 5, Des Allemands, La.

land and Lockport. It seems to be the result of the decay of the usual growth of prairie grass, but has considerable silt mixed in with the decayed vegetable matter and lies on a subsoil of typical Mississippi River silt, of chocolate-brown color. Owing to the slight elevation of the land it is quite soft, since it has never had a chance to drain and become solid. The front part is not cut up to any extent by bayous, although the tract includes a lake with an area of nearly 5 square miles.

The greatest problem to be solved in the reclamation of this tract is the protection against storm tides. The maximum rise in tide at this point is between 5 and 6 feet. This is higher than any on record for a period of about 100 years previous to the storm of September, 1909, which gave this maximum height.

Area No. 6 contains 2,000 acres of open grass-covered prairie taken from the above-described tract of land and in addition contains 500 acres of a river-front plantation. It is so located that an addition to it can be made on the west side if the pumping plant proves larger than necessary.

Levees.

The levee on this tract has been raised to a height of about 7 feet above mean tide level. The work was done with an orange-peel-bucket dredge, with a 70-foot boom. This allowed a berm of about 20 feet between the levee and the

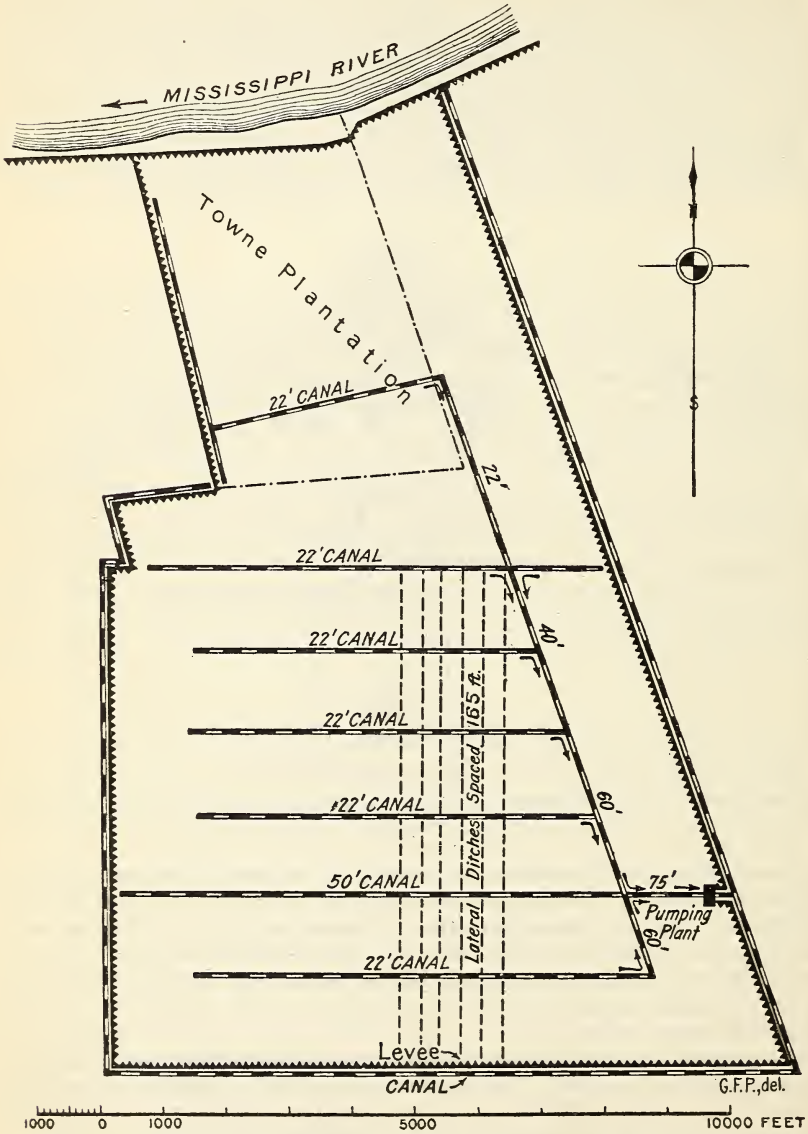


Fig. 14.—Sketch map of area No. 6, Poydras, La., showing ditch and levee systems.

canal. As shown in figure 14, all levee canals are on the outside, as the material was considered to be too soft to permit placing of the canal inside the district, and thus use it as a reservoir canal. By locating these canals on the

outside they will be made useful for navigation. For the most part there was no preparation of the base of the levee, for when the first few dippers of material were placed in the levee it cut very deeply into the muck and formed a good bond with the underlying silt. In placing the first layer no attempt was made to get much above 3 feet in height, but a wide base of 60 feet was secured for the remainder of the levee. In crossing some old drainage canals that had been cut for about 40 years, a decided difference was noted in the solidity of the material. Due to the small elevation of the surface along these canals they could furnish but very little drainage, yet in building levees across them it was noticed that they had affected the ground for a distance of several hundred feet, and that the levee could be raised in one layer to a height of about 6 feet above mean tide. This shows the advantage of allowing the first layer of material to drain for some time before placing the upper one. Most of the levee was brought to its present grade line with three layers of material, while in the soft portions it was necessary to place about five layers to bring it to grade. The levee at present seems to be holding to grade, and any further subsidence will be due to the decay of the vegetable material in the levee rather than to the spreading or subsidence of the base. Approximately twice as much material was excavated as will show in effective volume in the levee. The top width is at present about 4 feet, and the side slopes are 3 to 1. Thus far no seepage through this levee is apparent.

Reservoir Canals.

This tract has a very complete set of reservoir and collecting canals. The sizes of the various canals were more or less proportioned to the amount of water that they would be expected to carry when draining the adjacent land and taking the water from the connecting canals. Thus practically the same degree of drainage should be secured in all parts of the entire district, and the loss of head when the pumps are in operation should be about as small as is practicable. The greatest length necessary for any ditch is about one-eighth of a mile. These canals alone should give the ground fairly good drainage, at least until the muck begins to decay and becomes more impervious than at present. The storage capacity of these canals when the water is lowered to a distance of 4 feet below the surface is about 0.75 inch; at a distance of 3 feet it would be 0.52 inch. It is intended to hold the water at the 3-foot level, and even at this level the reservoir capacity of this district will be as large as that in the average district where the capacity is all excavated. A depth of about 7 feet has been given the collecting canals, and as the larger canals are reached, near the pumping plant, a depth of about 10 feet is attained. Due to the great depth of muck these collecting canals finally will have to be deepened, for when 4 feet of muck has decayed the surface of the ground will be lowered perhaps 2½ feet. This subsidence will, however, take a long term of years, and by that time the canals will have required cleaning several times, so that the increased depth of canal need not be made all at once.

These canals were all cut with a dredge of the hydraulic type. They are much more satisfactory than those cut with an ordinary dipper or orange-peel-bucket dredge, as they are left free from any soft mud and no great spoil bank is present on each side of the canal. In digging lateral ditches into these canals the expense of cutting through the spoil banks will be avoided and a considerable area of land usually wasted by being covered with excavated earth will be saved. The canals themselves should be more permanent, as the absence of a great weight on each bank will greatly decrease the tendency of the

material to flow into the canal. The surface is raised between 1 and 2 feet for a distance of 100 or 200 feet back from the canal banks by the deposit made by the hydraulic dredge. The cost of cutting the canals by this method is not as great as with the other type of dredge and the results are much more satisfactory. It is expected that in the future this type of dredge will be used almost exclusively where the ground is free from trees and stumps.

Ditches.

The spacing of the ditches on this tract is 165 feet. With the canals at one-half the usual distance, and with a deep, porous muck soil, this spacing should give a sufficient amount of drainage for a number of years until the soil becomes more impervious, due to the decay of the vegetation it contains. Owing to the soft nature of the soil in this district a long time would have been required for it to become solid enough to use the ordinary type of apron traction ditcher. A capstan ditcher, or ditching plow, was therefore used to cut the ditches. The plow was pulled with cables running between two adjacent collecting canals. In each of the canals an engine with winding drum was mounted on a barge. After cutting a ditch the barges were floated along the canals to the location of the next one. In some of the softer portions this plow was found to be too heavy and plowed too deeply, so a lighter structure of wood was substituted which cut a very satisfactory surface ditch. This tract is free from logs and stumps, thus allowing the use of such machinery. When the surface has become fairly solid, due to the drainage afforded by these superficial ditches, the larger and heavier ditching plow can be used, and all of these ditches will be put down to a depth of 3 feet. By this method of ditching the time consumed in placing the tract under complete drainage will be considerably lessened, for a wait of several months would have been necessary before a traction ditcher could have been used.

Pumping Plant.

In location this plant is rather far to one corner of the tract, but due to the large size of the main reservoir canal no great loss of head should result in the canals when the pumps are in operation. The greatest distance that the water will travel in the canals to reach the pump is about 3 miles. The pumps discharge into the navigation canal that surrounds the district and connects with the bays and bayous to the rear.

The machinery consists of one 36-inch and one 24-inch cast-iron centrifugal pump direct connected to slide-valve engines. The boilers are of the return-tube type and oil is used as fuel. The discharge and intake pipes on both pumps are enlarged to save the usual loss of velocity head. The two units are mounted on separate concrete foundations, supported on piling, the foundation forming part of the dam across the outfall canal. The greater part of the dam is of mud held in place by the rows of sheet piling that form the cofferdam. This saves considerable expense for concrete and still insures a water-tight dam. It is planned to use the small unit in times of ordinary rainfall and to use both when necessary. The combined capacity of the pumps when operating at full load will be about 1.1 inches in depth in 24 hours. On account of the high tide to be expected in this vicinity, the pumps are capable of working against a 10-foot head. The capacity will of course be greatly reduced at this head.

The building over this machinery is of fireproof construction, being a framework of structural steel covered with heavy corrugated galvanized iron.

AREA NO 7, GUEYDAN, VERMILION PARISH, LA.

This district, containing 5,600 acres, is the first one being developed in a tract of some 90,000 acres lying in the southern portion of Vermilion Parish and bordering on the northern shore of White Lake. The general nature of the soil and other natural conditions have already been described. The elevation of the surface above mean tide level is between 2 and 4 feet and the slope of the surface is from north to south. This tract is a typical example of the higher and firmer prairies of this section as contrasted with those of the softer type immediately along the rivers of this part of the State. (See Pl. II, fig. 1.)

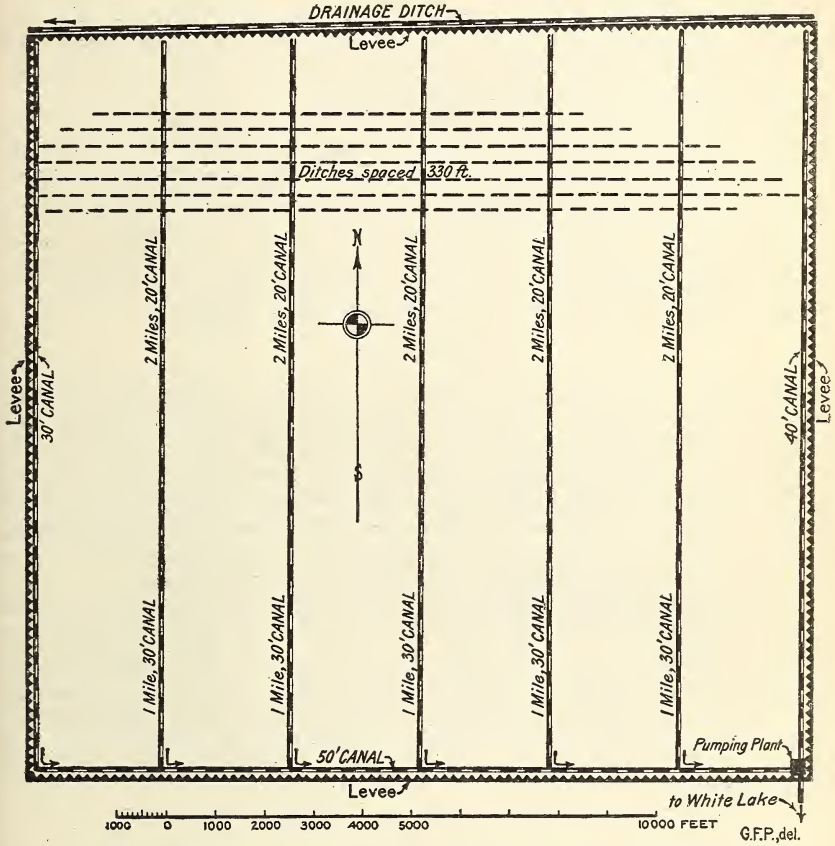


FIG. 15.—Sketch map of area No. 7, Gueydan, La., showing ditches and levees.

Work was begun on this district in June, 1911, and the pumping plant was started about March, 1912. Figure 15 shows the general arrangement of canals, levees, and ditches.

LEVEES.

Along the north side of this district a drainage canal had been cut some years previous to the beginning of the present work. A spoil bank of a cross-sectional area nearly sufficient to serve as a levee still exists on the south side of this canal. Along the other three sides the levee canals are on the inside of the district. In cutting a 25-foot canal 5 feet deep more than enough material

was secured to build a levee with a height of 5 feet and a top width of about the same. Owing to the solid nature of the subsoil, the levee as a whole subsides very little except for the usual shrinkage of the material itself. The slight depth of muck also contributes to this favorable condition. In a few places, however, some old muck-filled bayous have been encountered and the levee remaining after one trip over with the dredge is only about 2 feet high. It will be necessary to go over these spots several times to get the required height. The berms left by the dredges doing the work are not much over 8 feet. No muck ditch is being used under this levee. Taking into consideration the facts that the base of this levee is from 3 to 4 feet above mean tide, that the storm tide in this vicinity is not more than 2 feet, that the subsoil is very solid, and that the muck is only about 1 foot deep, it would seem in this case to be the best practice to place the levee canals on the inside of the district and thus to have use of them for drainage canals.

The levee should be certain protection from storm tides that occur in this section and should also cut off practically all seepage into the district. On the other hand, as all the canals are on the inside of the district their usefulness as navigation canals will be impaired. In the development of a district of this size the advantage of having navigable canals all around it is considerable. On newly reclaimed lands the question of water transportation is one of importance, as roads are very hard to construct when the land is first drained. It is the intention to use the levee as a road for most of its length.

Reservoir Canals.

In addition to the canals that border this district a collecting canal has been cut every half mile throughout. These collecting canals are about 7 feet deep and the reservoir is of about the same depth at the upper end and 10 feet deep at the lower end. In this soil these canals should maintain their original depth and there should be no trouble from the flow of the earth when the canals are first pumped out. The canals are of ample cross section to insure a small loss of head when the pumps are in operation. When the water is lowered to a level 4 feet below the surface the storage capacity will be 0.75 inch.

A lock has been built at the end of the main reservoir so that barges can be floated into the district. The depth of 10 feet in the main reservoir will allow navigation even when the water is low enough to give drainage to the entire tract. This district has one of the largest excavated reservoir capacities of any of the districts so far attempted. The frequent and regular lateral canals make it an easy matter to install an efficient ditch system. Plate III, figure 1, shows a dipper dredge cutting reservoir canal and building levee on this district.

Ditches.

Lateral ditches were cut on this district with an apron traction ditcher at a uniform spacing of 330 feet. (See Pl. III, fig. 2.) These machines worked on this district in from 1 to 3 feet of water. Owing to the solid nature of the soil the apron wheel did not sink into the ground to any great extent. Unlike the districts that are being reclaimed in the vicinity of New Orleans, the soil will not need to be drained for about two years before it becomes solid enough to cultivate in the ordinary manner, and this district should come under cultivation quite soon after the system is installed. However, the old muck-filled bayous will be soft for perhaps two years after the rest of the land is under cultivation. In these bayous the muck is about 5 feet deep. The area of this district that is in canals and ditches is about 3.2 per cent of the whole.

Pumping Plant.

This plant was located far in the corner of the district so as to place it directly on the main outlet canal to White Lake. If the plant had been placed in the middle of the south side the greatest distance that the water would travel to the pump could have been reduced from 6 miles to 4½ miles. The length of outlet to White Lake would have been increased, however, so that the actual gain in decreased lift would have been very small.

There are two cast-iron centrifugal pumps, having diameters of discharge opening of 54 inches (fig. 16). The pumps have double intake pipes and both the intake and discharge pipes are tapered and enlarged to four times the area of the opening on the pump, and they discharge under water. These features cut the velocity head losses to about the smallest amount that would be economical. There are two engines of the Corliss type, having 16 by 36 inch cylinders; these are direct connected to the pumps. (See Pl. IV.) Return-

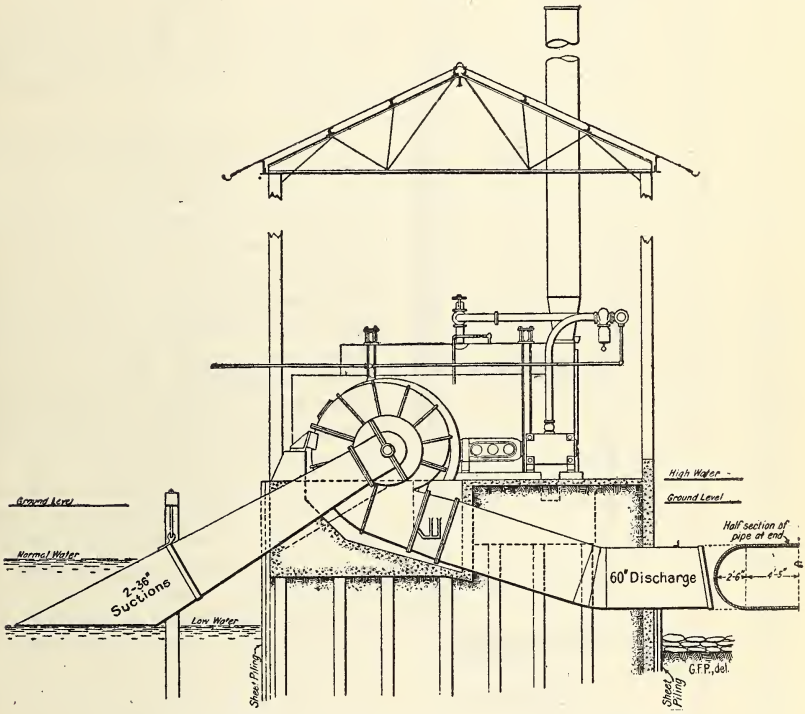


Fig. 16.—Elevation of pumping plant on area No. 7, Gueydan, La.

tube boilers are used, with oil as fuel. The machinery is mounted on a concrete foundation supported on piling. In driving these piling the subsoil was found to be very hard and the foundation should therefore be solid. When the plant is run at its full capacity the pumps will be able to remove about 1.50 inches of water from the 5,600 acres in 24 hours. By running the plant at an overload this rate can be increased a small amount. In case this proves to be a larger capacity than necessary an additional area of land will be brought into this district on the west side.

The building inclosing this machinery is a frame of structural steel, covered with heavy corrugated iron, and the plant is of fireproof construction throughout.

AREA NO. 8, NEW ORLEANS, LA.

This tract of land (fig. 17) lies within the city limits of New Orleans. It contains 1,085 acres. The district originally was a part of the swamp, and had a heavy growth of several varieties of trees, although the predominating variety was cypress. There is a deep layer of muck on this tract, quite similar to the usual wet prairie muck, except that it contains a large percentage of leaves and twigs. Underneath this layer of muck is a subsoil of very sandy material that is quite porous. The growth of trees has been almost entirely cut, but as a whole the land is not cultivated and is allowed to grow up in weeds and brush. About 10 per cent of the area is now taken up by improved city lots.

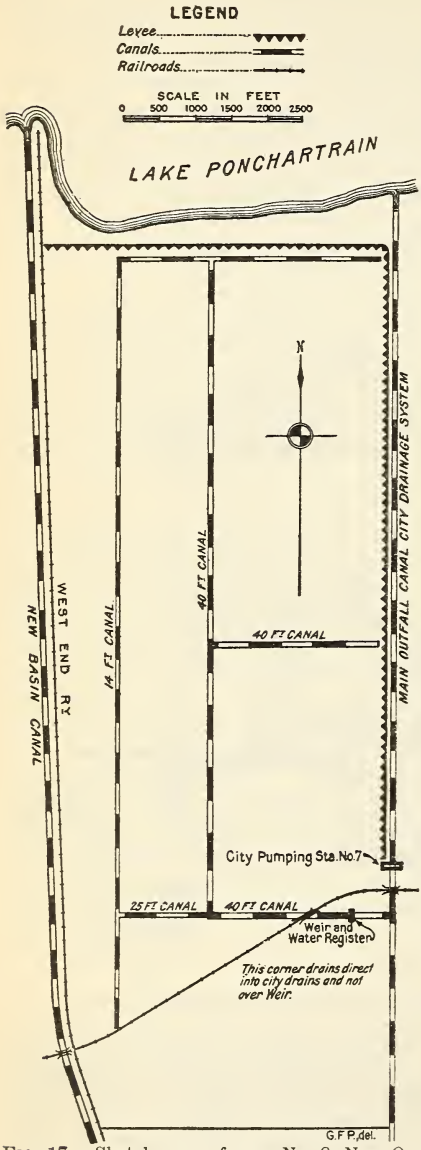


FIG. 17.—Sketch map of area No. 8, New Orleans, La., showing arrangement of ditches and levees.

The tract was inclosed by levees about five years ago. The levee along the canals was built a number of years earlier and the work was done by dredge. This levee has a width of from 20 to 40 feet on top, that part along the west side being used as a grade by the West End Railway, and that along the east side as a highway. The levee along Lake Pontchartrain was built with wheelbarrows, of a soil that is very porous and contains a high percentage of vegetable material, and as there is a canal quite close to the inside slope it is reasonably certain that the seepage is considerable. The fact that underlying this thick layer of muck there is a subsoil of porous sand would make seepage probable, not only under the small levee along the lake, but also under both wide levees along the canals. The interior drainage canals have been cut to the sizes shown in figure 17, and have been maintained nearly to their original size. Their average depths are from 6 to 8 feet. About 2 feet of water is kept in the canals to check the growth of vegetation. No extensive system of lateral ditches has yet been constructed on this tract, only a few in the immediate vicinity of the improved section having been dug; these, however, drain but a small percentage of the total area. When the entire tract is well drained

Area No.	Parish.	Town.	Area.	Depth of muck.	Elevation above mean gulf.	Height of storm tide.	Height of levees.	Spacing of laterals.	To[1]
			Acres.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Fee*
1	Jefferson.....	Waggaman....	2,600	0 -3	−2-9	None.	5	100 450	
2	La Fourche...	Lockport.....	647	0.5-2	−2-2	2	4	160	
3	.....do.....	Raceland.....	940	1 -2	0-3	2	4	200	
4	.....do.....	.....do.....	2,400	1 -2	0-3	2	4	210	
5	.....do.....	Allemands....	1,880	0 -1	0-2	2	4	210	
6	St. Bernard...	Poydras.....	2,500	4	0-1	6	7	165	
7	Vermilion.....	Gueydan.....	5,600	0.5-1	1-4	2	5	330	
9	St. Mary.....	Morgan City..	15,600	0 -1.5	1-6	4	6	330	
10	St. Charles....	Paradis.....	2,840	0 -2	0-3	2	4	330	
11	La Fourche...	La Rose.....	640	0 -3	0-3	3	4	210	
12	.....do.....	.....do.....	2,560	0 -3	0-3	3	4	210	
13	.....do.....	Golden Meadows.	1,780	0 -2	0-2	5	6	200	

[1] Maximum

the run-off probably will be more rapid than at present. The drainage water discharges by gravity through the main outlet canal into the city drainage canal. The run-off from this tract is more natural than would be the case if a pumping plant were operated. To measure this discharge a 6-foot weir was installed in the outlet canal, and a continuous record of depth of flow secured by use of a special recording device.

RESULTS OF INVESTIGATION OF RECLAIMED TRACTS.

In the table facing this page is given a summary of all the details of reclamation and the prominent natural conditions on areas herein described, with corresponding data on a number of other districts. No detailed descriptions of these latter districts will be given, as conditions occurring on them are in general similar to those on the districts already described.

In explanation of this table the following notes are given:

In calculating the percentage of land that is in lateral ditches it was considered that for each ditch a strip 6 feet wide is lost to cultivation.

The reservoir capacity, in inches of depth over the whole area, includes the capacity of all canals between the general surface of land and the water level 4 feet below the surface.

The pumping plant capacity was based on a velocity of 12 feet per second through the discharge opening of the pump.

AREA.

The districts examined range in size from 640 acres up to 15,600 acres. The newer districts are nearly all among the larger-sized ones, the present tendency being toward larger districts. On some of the districts the shape and area were fixed according to the surrounding natural water channels, but most of them were fixed arbitrarily, as the surrounding marsh was level and unbroken by open water. With the increased size, the shape and boundaries of the districts will be more and more influenced by the topographic features of the marsh. So far, the districts have been rather small, as, owing to the limited capital available, it was necessary to get them under cultivation soon after the work was started.

SOIL.

The general nature of the soil in these tracts has already been discussed. In reclaiming the land no particular attention was paid to the character of the soil, except to the depth of muck overlying the silt. The figures given in the foregoing table show the range in depth of muck on the several tracts, the mean depth on these districts usually being an average of the two figures given. A considerable subsidence of the surface of the muck land takes place after drainage, this often amounting to as much as 75 per cent of the original depth of the muck. As pointed out in the description of area No. 1, the subsidence amounted to about 2½ feet in 12 years of drainage. None of the other districts has as yet shown much subsidence, as they have not been drained or cultivated a sufficient length of time.

LEVEES.

The levees vary in height according to the storm tides that are encountered, although it is generally admitted that a height of about 4 feet is necessary to prevent seepage. Almost without exception the heights of the levees are sufficient to keep out the recorded high tides, although in the interior sections the fluctuation of water in the natural channels, due to rainfall, is greater than that caused by storm tides from the Gulf. The top width is usually from 5 to 10 feet. In many places levees are used as the main roads of the district; in

Summary of natural conditions and drainage features on 12 reclamation districts in southern Louisiana.

Area No.	Parish.	Town.	Area.	Depth of muck.	Elevation above mean gulf.	Height of storm tide.	Height of levees.	Spacing of laterals.	Size of laterals. Top.	Size of laterals. Bottom.	Size of laterals. Depth.	Length of laterals.	Depth of water table.	Land in ditches.	Land in canals.	Reservoir capacity.	Pumping capacity in 24 hours.	Pumps.	Engines.	Boilers.	Fuel.	Work begun.	Date of first pumping.	Date of first cultivation.	Cultivated in 1912.	Remarks.
			Acres.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Per cent.*	*Per cent.*	*Inches.*	*Inches.*								*Per cent.*	
1	Jefferson	Waggaman	2,600	0 -3	−2-9	None.	5	100 450	3	1½	3	2,400	1½	3.80	2.00	0.37	[1] 1.45	1 rotary 1 Menge, 42 by 16 inch 1 centrifugal, 36-inch	1 vertical 2 slide valve horizontal	2 water tube 1 return tube	Oil	About 1898	About 1899	About 1900	100	
2	La Fourche	Lockport	617	0.5-2	−2-2	2	4	160	4	1½	3	5,280	2	3.30	.94	.45	[1] 1.11	Menge, 32 by 12 inch; 24 by 8 inch.	Slide valve horizontal	Return tube	Oil	1907	1908	1908	90	
3	do	Raceland	940	1 -2	0-3	2	4	200	4	1½	3	2,000	2	2.90	.47	.25	[1] 1.23	2 Menge, 32 by 12 inch	Slide valve	Locomotive	Coal	1907	1908	1909	65	
4	do	do	2,400	1 -2	0-3	2	4	210	4	1½	3	1,200 2,000	2	2.50	.83	.40	1.20	2 centrifugal, 30-inch	Slide valve vertical	Return tube	Oil	1908	1910	1910	30	
5	do	Allemands	1,880	0 -1	0-2	2	4	210	4	1½	3	2,000		2.60	1.00	.50	.95	2 centrifugal, 24-inch	do	do	Oil	1910	Sept., 1911	1912	10	
6	St. Bernard	Poydras	2,500	4	0-1	6	7	165	4	1½	3	660		3.30	1.50	.75	1.17	Centrifugal, 24-inch, 36-inch	Slide valve horizontal	do	Oil	1910	Mar., 1912		None.	
7	Vermilion	Gueydan	5,600	0.5-1	1-4	2	5	330	4	1½	3	1,320		1.70	1.50	.75	1.51	2 centrifugal, 54-inch	Horizontal Corliss	do	Oil	1911	1912	1912	2	
9	St. Mary	Morgan City	15,600	0 -1.5	1-6	4	6	330	4	1	3	1,320		1.80	3.80	1.82	.87	2 centrifugal, 30-inch, 3 48-inch.	Cross compound condensing.	Water tube	Oil	1911	1912	1912	4	Plant partially installed.
10	St. Charles	Paradis	2,840	0 -2	0-3	2	4	330	4	1½	3	1,320		1.50	.94	.45	1.40	2 centrifugal, 36-inch	Slide valve horizontal	Return tube	Oil	Jan., 1910	Aug., 1911		None.	
11	La Fourche	La Rose	640	0 -3	0-3	3	4	210	4	1½	3	2,640		2.00	.56	.27	1.30	1 centrifugal, 15-inch, 1 18-inch.	2 gasoline, 40-horsepower			1910	1911	1911	80	
12	do	do	2,560	0 -3	0-3	3	4	210	4	1½	3	1,320 2,640		2.90	1.00	.48	1.50	2 centrifugal, 36-inch	Slide valve vertical	Return tube	Oil	1910	Sept., 1911		None.	
13	do	Golden Meadows.	1,780	0 -2	0-2	5	6	200	4	1½	4	1,320		2.80	1.25	.60	[2] 1.00	Centrifugal				Aug., 1912			None.	Under construction.

[1] Maximum.

[2] As designed.

these cases the crown is somewhat over 10 feet. The maintaining of a road on a levee seems to aid in keeping out muskrats and other burrowing animals, but gradually decreases the height. The side slopes are usually quite flat, being about 3 to 1. In very few of the levees had any preparation been made for the base, either by clearing away vegetation or by cutting muck ditches. Where both the muck and subsoil were very soft, seepage through the base was not noticeable, but where the muck was turfy in character nearly all the levees developed seepage when the berm on the outside of the levee was submerged to any considerable depth. Seepage appears to increase in volume as the muck in the levee decays and shrinks; thus in some cases the older levees were not keeping out the water as well as they did at first. It has been necessary to cut muck ditches along many of these old levees to intercept the flow of water through their bases.

The majority of these levees were constructed with some form of dredge. The unit price for material, measured in excavation, was in the neighborhood of 7 or 8 cents per cubic yard, depending on the amount of timber and stumps encountered. It is always necessary to place more material in a levee than the final cross section indicates, owing to subsidence of the base and shrinkage of the material. This shrinkage will require from one and one-half to three times as much excavation as the final volume of the levee. The unit cost of levees will therefore vary from 12 to 25 cents per cubic yard, measured in settled embankment. If the levee is brought to a regular cross section by hand or machine work a small additional charge should be made; generally, however, the embankments are not surfaced after the dredge work is finished.

The natural growth of prairie grass soon covers the majority of the levees, and some of them have been sown to Bermuda grass. The levees are often pastured, and when this is done with care it affords an efficient and a profitable method of maintenance.

DITCHES.

The spacing of the ditches has been varied on the different districts according to the nature of the soil. Some of these are spaced too far apart to give adequate drainage, but, on the other hand, on none of the districts are the ditches too close together for economy; that is, the land is in no case overdrained. A spacing of 330 feet on newly reclaimed lands seems to be popular, with the idea of making the spacing 165 feet when the land becomes more impervious, due to the decay of the vegetable matter. The size of the ditches is quite uniform and is usually ample, except where the ditches are too long. The efficiency of these small ditches as water channels is very low, for they are usually partly filled with weeds and grasses. As most of the land is flat, flow is caused only by the piling up of drainage water in the ditch. A length of about a quarter of a mile has been found to give satisfaction in flat land, and when there is any considerable slope to the ground much longer ditches have been used with entire success. The use of the 6 to 8 foot collecting ditch to take the water from the laterals has not proved a success on the marshland districts, the maintenance charges being too great. The percentage of land taken up by these lateral systems is usually between 2 and 3 per cent. The cost of their excavation has been between 5 and 6 cents per cubic yard, and with a spacing of 330 feet the cost of the ditches per acre has been between $2 and $2.25.

GROUND WATER.

The ground water is controlled largely by the depth of the lateral ditches. Even though the subsoil be very fine grained and impervious, there is a considerable lateral movement of the water, as was shown by measurement of the

profiles of the ground water made on areas Nos. 1 and 2. (See figs. 5 and 8, pp. 26 and 31.) The slope of the ground-water profile is steep after a heavy precipitation and gradually flattens out after a few days of dry weather. Evaporation at the surface hastens this lowering of the water table, and measurements show that the profile of the ground water is usually much flatter in the summer months than in winter. In removing the ground water the effect of a ditch decreases toward the middle of the strip of land between the ditches, while the effect of evaporation is more or less uniform over all this strip of land, although it depends somewhat on the depth of water below the surface. The actual evaporation is greatest midway between the ditches, where the water is nearest to the surface. The variation between the summer and winter slopes of the ground-water profile is therefore due to the difference between the combined effect of the ditch and evaporation in summer and the effect of the ditch alone in winter, as evaporation is then comparatively very slight.

After long periods of small precipitation and high temperature the water is often lowered by evaporation below the bottom of the ditch, but at these times the ground water is nearly level, as the effect of the ditch is then almost entirely eliminated. It was also noted that the ground water was reduced to lower levels by evaporation in the fine-grained silt soils than in the coarser muck soils.

RESERVOIR CANALS.

The reservoir capacity is as variable as the size of the district. No attempt seems to have been made in the earlier districts to provide reservoir capacity, all ditches being constructed as drainage channels. Even this feature was not sufficiently provided for in the earlier districts, as the canals were not of sufficient cross section to bring the water to the pumping plant rapidly enough to secure continuous operation. The resulting large slope of the water surface in the canal and the consequent loss of head acted directly on the pumping plant to increase the lift. The present tendency is toward increased storage capacity, with deeper and wider canals. The loss of head during the operation of the pumps is thus partly overcome, and in addition the plant is not required to operate so intermittently. Some of the smaller canals on the older and smaller tracts are so shallow as to allow vegetation to grow on the bottom, and, moreover, the small deposit of mud from lateral ditches fills the bottoms of the canals above low-water line and thus checks the flow. With a greater depth a small deposit of silt would not have such great influence on the efficiency of the canals and vegetation would not grow so readily on the bottom. In many of the new districts the slope of the water surface in the main reservoir is calculated to be as low as two-tenths of a foot per mile when the pumps are operating at full capacity. However, this slope increases as the water lowers and the cross-sectional area of flow decreases. It has been observed that the larger reservoir capacity takes care of the smaller rains and that the pumps therefore do not need to be started for them; it also appears that at times of heavy precipitation the reservoir takes a part of the run-off and decreases the amount of water that must be removed at once by the pumps. It is a notable fact that the largest district has the largest reservoir capacity. This is due to the fact that a number of large and deep natural water channels were included in the district. It is the only one of the enumerated districts where such a feature had been included in the drainage plans.

The maintenance of reservoir canals in these soils for the first few years has proved to be quite an item. When the water is first lowered it must be done very slowly and with great care to prevent caving of the banks and general shrinking of the cross section of the canals. A deposit of silt will occur, and

in many cases it has been found necessary to redredge the canal about three years after construction. The surrounding land is then solid enough approximately to hold its place and to make the canal permanent. Canals constructed with a hydraulic dredge are better cleared of soft mud at the time of construction, and, due to absence of heavy spoil banks close to the edge of the canal, appear to hold their original size more satisfactorily than those constructed by other forms of dredge.

On the newer districts the area in canals is about 1 per cent of the area included within the levees. The average cost per cubic yard for cutting internal canals is between 6 and 8 cents, the higher figure being applicable to cases where the ground is covered with a growth of timber, when the work is done with a dipper dredge. If the land be free from stumps and sunken timber the work can be done either by dipper dredge or hydraulic dredge for about 6 cents per cubic yard.

PUMPING PLANTS.

The theoretical normal capacity of the plants examined averages 1.22 inches in depth of water over the whole area removed in 24 hours of continuous operation. On most of the districts the normal capacity can be increased somewhat by speeding up the machinery. The reservoir capacity and pumping-plant capacity are not proportioned to each other at all uniformly. There is such a wide variation in this regard that either some pumping plants are too large to be economical, or a number of the others are far too small to give drainage. As little flooding of any of these districts has occurred, it would appear that the former is true. There is as much variation in capacity in the newer plants as in the older ones. No settled policy as to required capacity has been established. Some plants have been built of ample size, so that if it became apparent that more water could safely be handled an addition could be made to the area drained. In the summary (facing p. 53) it will be noted that the smallest pumping-plant capacity appears on the largest district, which district has the largest reservoir capacity. Even the smaller plants have their pumping capacity divided between at least two units. This allows the use of part of the plant during low-water flow, with as small capacity as is desired. In some of the plants which consist of two duplicate units each unit is nearly large enough to take care of all the water; this provides a reserve capacity in case of breakage of one of the units.

The static lift in these pumping plants varies from 3 to 10 feet. The bulk of the water usually is lifted only about 3 feet, the lift increasing as the water in the canal is lowered, so that it is only during the last few hours of pumping that the lift approaches the larger figure given.

The cast-iron centrifugal pumps are largely used and have been found very much more satisfactory than the older types of vertical wooden-case centrifugal pumps. While the first cost of the latter type is less than that of the cast-iron pump the efficiency also is less, and the maintenance much greater. As pumps of the vertical wooden-case type can not be direct connected to engines they are not so reliable in operation, and as they do not discharge into a closed pipe no siphon effect can be arranged, and their actual lift usually is from 2 to 3 feet greater than the effective lift. Also they do not lend themselves well to installation on a concrete foundation.

Only one rotary-pump installation was examined, and while the pump operates very satisfactorily it was lifting the water fully twice the necessary height. Rotary pumps of the desired capacity are adapted to a minimum lift of about 10 feet, and as the usual lift is about half this amount the loss of energy is far too large. All the modern plants are equipped with horizontal

cast-iron centrifugal pumps, this type having proved to be very reliable. Continuous runs of 140 hours have been made without trouble.

On most of the pumps the suction and discharge piping has been so arranged that the friction losses are small, and the areas of intake and discharge openings of the pipes have been enlarged to decrease velocity head losses. On some plants this velocity head loss often amounts to 4 feet, and as a result the plant does nearly twice the amount of work necessary. The piping of the centrifugal pump on area No. 1 and on two pumps on area No. 11 is not enlarged or tapered, and there are large losses due to this defect. All of the more modern pumps have large intake and discharge openings, and the pipes often are tapered the full length. When the suction ends of the intake pipes are cut vertically whirlpools will develop over the pipes and air will be admitted, even when the water is 2 feet deep over the pipes. If these pipes be cut horizontally the water can be lowered to within an inch of the ends of the pipes before air enters.

On the smaller and older districts simple and reliable engines have been used, but most of them have a very large steam consumption. Reliability and low first cost have been sought, but, due to low-class labor, many of these plants have had frequent breakdowns and large repair charges. A few of the large districts are installing high-class machinery, and one, as shown in the summary, has installed cross-compound condensing engines and water-tube boilers. Gasoline engines have been used on one small plant only, and although fairly satisfactory no general use of them is expected.

Owing to the mild nature of the climate very few of the plants have been inclosed in permanent structures. Timber frame structures covered with heavy corrugated galvanized iron are very common among the plants, and while these are quite durable the danger from fire is very great. Two plants of this type have recently burned.

The cost of such plants as those described ranges from $4 to $7 per acre of the district drained, according to the type and the capacity of the machinery.

VEGETATION AND DEPTH OF DRAINAGE.

As noted in the general description of this section, most of this land, whether salt or fresh-water marsh, is covered with a heavy growth of grass (see Pl. II, fig. 1). This seems to thrive even if the land is continuously submerged with a small depth of water. However, when the land is drained sufficiently to remove the water from the surface this grass grows much more luxuriantly, and has been cut for hay two to four times in a single season. It appears to grow better with deeper drainage. When cut for hay it makes excellent feed for stock, and is much in favor with all the local planters who have given it a feeding test. Deeper drainage is required for cane and corn, although fair crops of corn have been grown with only about one foot of drainage. It would appear that good crops can be grown if the water is held down to 2 feet below the surface, but all planters are of the opinion that the deeper the drainage the better, down to a depth of 3½ feet. The truck crops all require complete and early drainage, but not necessarily as deep as that required for cane and corn. As droughts are of rare occurrence, not much trouble has been experienced in getting the ground water too low in the soil. By proper management of the pumping plant the stage of water in the canals and ditches can be so arranged that the water will not be reduced too great a distance below the surface. This artificial control of the water content of the soil is of decided advantage, and it should make these lands as independent of natural conditions as are the irrigated lands of the West. Crops on the muck lands seem to withstand

drought better than those on the older sandy-land plantations, as the muck is more retentive of moisture.

TREATMENT OF LAND AND CROPS.

In general the water was lowered as rapidly as possible on these marshlands when they were first reclaimed. The lateral ditches were then constructed and complete drainage of the soil obtained. No trouble has been experienced from too rapid drainage. Although the muck often is covered with a very tough sod, and is itself often turfy in character, it is full of muskrat holes, and as it dries and shrinks during drainage a great number of cracks open that reach to the underlying soft mud. This has made it impossible in a great many cases to do the first work of plowing with ordinary farm animals and machinery. The land usually is plowed the first time with a set of gang plows drawn by some form of mechanical tractor. (See Pl. II, fig. 2.) It is necessary that the tractor be mounted on very wide wheels, and the substitution of apron traction for wheels has been made very successfully. Plowing has been done with these tractors on land that is too soft to bear farm animals. The heavy growth of prairie grass must first be removed. Usually the first plowing is done in the winter months when the grass can be burned off closely. A set of gang plows fastened to a frame hinged directly to the tractor frame has worked most successfully. After one thorough plowing of the ground with a gang plow the holes and cracks are so completely filled that ordinarily no trouble is thereafter experienced in using farm animals if the tract has been well drained during this period. It is very essential during the first few years of drainage that the water table be held at a good depth to allow the soft subsoil to solidify. This involves deep winter drainage, as well as during the growing season.

Usually the first crop planted is corn, and it is frequently drilled in by a separate drill attachment at the time of the first plowing. Sometimes this first crop makes a yield of 30 bushels to the acre without further cultivation. One plowing, however, does not kill the original growth of prairie grass. In fact, if the ground is once plowed the growth of prairie grass the next year will be more uniform and luxuriant than it was before. Intensive cultivation for the first few years is necessary, although in growing cane and corn no trouble is experienced after the crop has reached a height of 3 or 4 feet. As truck crops usually are cultivated very intensively, no great trouble is experienced in keeping down the growth of grass. After the growth of the first crop of corn the land is replanted to corn, cane, or truck crops. The soil seems to be suitable for almost any kind of truck, and excellent yields are harvested. Some 40 to 60 bushels of corn to the acre have been successfully grown, and the yield of cane varies from 25 to 40 tons to the acre.

Where the original surface of the soil was covered with a growth of cypress timber a large additional expense must be incurred in bringing the land into cultivation. The expense of clearing cypress land ranges from $30 to as high as $100 an acre, depending on the character of the growth. In certain sections of the prairie lands a very heavy growth of submerged stumps is found, and after the land has been drained for a year or two the shrinkage of the muck soil will bring these stumps to the surface. They will then interfere with cultivation very greatly and necessitate a large expenditure for removal.

FINANCIAL.

In its original state much of the prairie land is worthless, its only usefulness being in that it serves as a trapping and hunting ground. Its present market

value is due to possibilities of reclamation rather than to any present usefulness and is more or less speculative. The value of the land varies according to the completeness and permanence of the drainage improvements, as well as according to its original character. A wide variation in the quality of the improvements exists, especially in the pumping-plant equipment. The cost per acre of reclaiming the various districts depends on natural conditions, the completeness of reclamation, and the character of the drainage improvements. The usual variation in the cost of such reclamation is from $25 to $35 per acre.

SUCCESS OF DRAINAGE.

The drainage of these lands has been uniformly successful, and from the drainage engineer's standpoint the work is past the experimental stage. Where successful drainage has not been attained it has been due to insufficient and poorly constructed improvement rather than to inherent and insurmountable difficulties. Some districts have been drained without the advice and services of an engineer, and while in some such cases successful drainage has been secured, it was not secured with the greatest economy, the proposition that if enough money be spent the land can be drained being a self-evident one.

The usual faults in the drainage systems are—

(1) Poorly constructed and leaky levees.

(2) Poorly constructed and inefficient pumping plants.

(3) The lack of sufficient canal capacity to drain successfully the interior of the tract.

INVESTIGATIONS TO BE MADE BEFORE RECLAMATION.

Before attempting to reclaim any district of marshland, the following points should be thoroughly investigated:

(1) The depth and character of the muck.

(2) The character of the underlying silt.

(3) The elevation of the land above ordinary stages of water in the surrounding lakes and bayous.

(4) The ordinary and extreme variations of water level in these lakes and bayous.

(5) The elevation of the ordinary and maximum storm tides.

(6) The existence of sunken timber and stumps.

(7) Transportation facilities.

In addition to the above, the topographic features of each district should be investigated in detail by a careful field survey and a complete and definite plan worked out by a competent engineer. The work should then be constructed under competent supervision and should be of a permanent nature, since the need for the improvements will be permanent.

FACTORS AFFECTING DRAINAGE BY PUMPING IN SOUTHERN LOUISIANA.

While the feasibility of reclaiming these wet lands has been demonstrated beyond question, there are a number of details of practice that have not yet been satisfactorily worked out, and it is not possible at this time definitely to recommend a line of procedure that will result in the most efficient and economical drainage of any tract of wet prairie land. In the following pages are discussed briefly each of the important items that enter into this form of reclamation. The conclusions presented are necessarily based upon a study of a rather limited practice, and further experimentation and investigation may alter somewhat certain of the recommendations herein made.

AREA OF THE DISTRICT.

Although in many localities topography has a large influence in fixing the area of a reclamation district, there are many large bodies of land of such a character that the size of the unit would be determined almost entirely independently of topographic conditions. In order to make clear the conditions governing the determination of the most desirable size of unit, the respective advantages of the small and large districts will be enumerated. The principal advantages of the small unit are:

(1) Short internal drainage canals with small losses of head and the consequent low lift.

(2) Short haul to outside water transportation.

(3) Small area affected in case of failure of protection levee.

(4) Small capital involved.

(5) Short time required to place land under cultivation and early realization on investment.

The advantages of the large district over the small one are:

(1) Low cost of levees per acre of protected land.

(2) Possibility of using natural ridges in part for levees.

(3) Possibility of using natural bayous and lakes as part of the interior drainage system.

(4) Use of efficient machinery due to more continuous operation of the pumping plant.

(5) Low first cost, per unit of area, of pumping plant due to centralization of equipment and smaller relative capacity.

(6) Low unit operating charges on pumping plant.

The benefit of low lifts on the smaller districts is offset by the advantages in using more efficient machinery for the high lifts on larger districts and the less cost per acre of machinery. Unit labor charges for plant operation also would be much less on the larger districts. Although the haul to water transportation on large districts would necessarily be greater, with larger interests involved good roads could be economically built and maintained. Since the cost of the levee per acre of reclaimed land would be much less on a larger district, a better class of levee could be constructed and breaks prevented. While at times the small district could perhaps take advantage of natural ridges, this would usually result in too much irregularity in shape and only in rare cases could the small district include natural bayous or lakes as reservoirs. The advantages, in the case of the small district, of the small capital involved and the earlier return on investment might easily be offset by the increased cost per acre of construction of levees, canals, and pumping plant. Just what is the most economical size of district has not yet been determined; it is a matter that would be greatly affected by local conditions. However, it is the consensus of opinion among engineers engaged in this work that districts containing less than 2,000 acres are not at all desirable. Most of the districts now being planned are several times larger than this. One of the newest districts, and the largest yet planned, lies just across the Mississippi River from the city of New Orleans and contains 37,750 acres.

LEVEES.

The location of a levee influences its design, construction, maintenance, and usefulness to the district. Unlike levees along our rivers, those along the average reclamation district in this section have not been located according to the topographic conditions, but rather according to property or land lines. This has usually resulted in regularly shaped districts and minimum length of

levee for area inclosed, but the cost of construction and maintenance per unit of length has often been much greater than it would have been if some attention had been paid to topography. Throughout most of the wet prairie there are winding bayous that have along them solid ridges of silt that average from 1½ to 2 feet above general ground surface. In other places the bayous are entirely filled in and there have been left ridges of silt having widths of from 200 to perhaps 1,200 feet, with the usual elevation of 2 feet. On small districts it is usually impracticable to take advantage of these ridges to any great extent, as to do so would make the shape of the district too irregular, but on larger districts the straighter ridges can be chosen, as irregularity of outline is not so large an item. If the levee is located on a solid ridge the material will be more stable and impervious and the levee can be made of less cross-sectional area than would be necessary if it were located in the soft prairie. Construction will also be easier and cheaper and the expense of maintenance will be much less.

The design of the levee will depend largely on the local conditions. Its top should be above storm tides and the highest stages of water in surrounding lakes and bayous from 1 to 3 feet, depending on the size of the district and the probability of previous high-water marks being exceeded. A minimum height of about 4 feet should be used through the soft prairie section, as anything less is not likely to prevent seepage satisfactorily, for when located on a ridge the water will stand against a levee only for short periods, while if located in a soft prairie the water will be in continuous contact with the lower foot or two of the levee. In places exposed to strong wave action the height should be sufficient to provide for the break of the waves; in addition, some provision should be made for protecting the levees from the erosive action of the waves. This protection might well be secured by planting willows some distance in front of the levee.

Where the levee is located on a ridge the top width may safely be made 4 feet, with side slopes 2 to 1. A levee of this type is often built with wheelbarrows, and although the unit cost for this method is quite high, being about 18 cents per cubic yard, the total cost is considerably less than it would be if the work were done with the usual floating dredge. Yard for yard the dredge would, of course, handle the material much the cheaper, but the excavation would be more than would be necessary for the levee. This objection would be overcome if the dredge were building a levee along the bank of a bayou of sufficient depth to float the machine, or if a reservoir canal were being excavated within the district, the waste bank to be used as a levee.

Where the levee is located in the soft prairie the top width should average about 6 feet. The side slopes should be about 3 to 1; in fact, if the material is very soft it will not take a much steeper slope than this during construction. As the material always becomes more stable after being placed in the levee, no trouble should be expected from slides after it begins to dry in place. The berm along the base of the levee should be at least 10 feet. Where the soil is exceptionally soft this should be made as much larger as practicable, at least 15 feet, and it will be better if conditions permit its being made 20. The width of berm will, of course, depend somewhat upon the nature of the machinery used in construction. Where the levee canal is on the inside of a district, special effort should be made to leave a wide berm.

Some type of floating dredge should be used in the construction of most levees. In heavily timbered sections, or where old submerged stumps are numerous, the dipper dredge will work to the best advantage, but in the open, grass-covered prairie the orange-peel-bucket dredge has many advantages. Owing to the longer boom and narrower hull, the latter type of dredge is able

to leave a wider berm along the toe of the levee. It is also better able to sort the material placed in the base of the levee, for the top layer of muck can first be taken out of the canal, and then the silt underneath, while the dipper dredge usually will cut up through both the silt and the muck and thus mix them. The levee should usually be constructed in several layers, for both the base and the material are likely to be so soft that subsidence will be too great if a height of more than a few feet is attempted. This yielding of the base often will cause the side of the canal to cave, especially if the berm be small.

The total subsidence and shrinkage of levees in this section often amounts to 50 per cent, and in special cases is as great as 80 per cent. Practically all of the subsidence and a part of the shrinkage takes place during construction, so that the remaining change in height can be taken care of by maintenance. When a large percentage of muck is placed in the levee the shrinkage will be great for a number of years, due to the decay of the vegetable material in the muck.

For placing several layers in a levee the orange-peel bucket is especially suitable. After a canal is once cut in the soft prairie there will be a considerable depth of soft mud in the bottom that makes very poor levee material.

The dipper dredge, when working in such a canal, will place a large percentage of such soft mud in the levee, while an orange-peel bucket, when dropped forcibly, will penetrate the undisturbed silt below and fill with it, the soft mud running off when the bucket is raised.

If the site of the levee is along a solid ridge above ordinary water level, no special precautions need be taken to prevent seepage, although all stumps and logs should be removed from the site, and a shallow ditch should be cut to insure a perfect bond between the ridge and the levee. On the other hand, if the levee is through very soft prairie, the material dropped from the dredge will penetrate the muck and form a good bond with the underlying silt. It is on the portions where the muck is thick and turfy in character that particular pains must be taken. A ditch cut along the center line of the levee before the dredge starts working is of no special benefit, as the material placed back in the ditch by the dredge will be largely muck; however, this treatment will break the continuity of the muck and help to cut off a portion of the seepage. A better plan is to wait until the first layer of material has been placed by the dredge and then to cut a ditch along the toe of the slope of the levee opposite to the dredge and to refill it with impervious silt dredged from the bottom of the canal. This will insure a good bonding of the material and is a necessary part of the construction. At times old muck-filled bayous will be encountered which must be closed with levees. In such cases the quickest, and quite often the cheapest, way to insure that the levee will hold its grade line is to drive two rows of sheet piling across the bayou at the proper spacing. These rows should be tied together with rods and the fill made between them.

After the soft material in the levee has dried sufficiently it should be smoothed off and brought to grade. Usually the natural growth of prairie grass will soon cover the levee, but Bermuda grass makes better sod for maintenance purposes. Careful grazing of the levee saves cutting the grass and gives partial protection from burrowing animals. After the levees are once constructed, very little maintenance is required to afford permanent protection from all overflows that do not actually overtop them.

INTERIOR DITCH SYSTEM.

Rainfall and seepage cause an accumulation of water within the levee district that must be collected by a system of ditches and canals, led to a central point,

and discharged over the levee by means of pumps. These internal water courses usually consist of lateral ditches which collect the water from the fields, and reservoir canals which receive the water from the laterals and carry it to the pumping plant.

Lateral Ditches.

On the typical wet prairie reclamation district the land is so nearly level that a regular layout of ditches is desirable rather than a location designed with a view to taking advantage of such slight surface slopes as may exist. The ditches should be cut in parallel lines and at such a spacing as will correspond to the character of the land. In the newly reclaimed land that has a deep layer of muck, ditches spaced 330 feet apart should give sufficient outlet both for surface and underdrainage, and after some years of cultivation, when the soil has become more impervious, intermediate ditches can be cut, making the spacing 165 feet. This divides the land into 5 and 10 acre tracts when the ditches are constructed in the usual lengths of one-fourth and one-half mile, respectively. Ditches with 4-foot tops, 1½-foot bottoms, and depths of 4 feet should give sufficient capacity unless they are too long or become badly choked with weeds and grass. In practice on drainage districts in this section it has been found that in flat land such ditches can be made one-fourth mile long with good results, and they have in a few cases worked fairly well at a length of one-half mile. However, this greater length is not recommended, as the ditch must be maintained in almost perfect condition in order to give satisfactory drainage. Such ditches can be cut by hand labor for about 5 or 7 cents per cubic yard.

Traction ditchers which will operate on soft prairies have been in use for some time and will compete with hand-labor prices and cut about the same class of ditch; however, where there is much sunken timber or stumps the work must be done by hand. On the softer prairies these traction ditchers can not be used until some months after the tract has been drained and the land has become somewhat solid. Ditches can be cut with a heavy wooden-framed plow, especially built for the purpose, drawn across the strips of land between the reservoir canals by cables and pulling engines mounted on barges. Ditches can be cut in this manner as soon as the water is off the surface, and thus the bringing of the land under cultivation will be hastened by several months. Field ditches on this class of land require a great deal of attention for the first few years after cutting to keep them serviceable. A soft semifluid mud gradually fills the ditches and water-loving grasses grow very rapidly. Where ditches have been cut with a plow they can readily be cleaned by drawing the plow through them. This method, however, will deposit most of the mud in the reservoir canal and will eventually reduce the area of the latter very materially.

Practice in this section has shown that to keep such ditches in a serviceable condition the grass and weeds should be cut out of them two or three times a year, and that every two years about 1 cubic foot of material per linear foot of ditch must be excavated. The total yearly cost, including interest on first cost, maintenance, and rental of land consumed in ditch, is about 55 cents per 100 feet of ditch, or $1.40 per acre for a spacing of 165 feet. In the firmer and more open soils tile might well be used to replace a considerable number of the ditches. The interest on the cost of such tile drains would amount to 30 cents per year for each 100 feet of drain; no maintenance or rental of land consumed should be charged. For a spacing of 165 feet this would make a charge of 80 cents per acre per year, or would be an annual saving of 60 cents per acre over open-ditch drainage. The action of efficient tile drains would also be more uniform. In the case of the ditch, during the time immediately before

it is cleaned out, the drainage secured is comparatively poor. The land would not be so badly cut up if tile were used, and the necessity for a great number of small bridges would thus be removed.

Reservoir Canals.

The primary requisite of reservoir canals is that they give sufficient outlet to the lateral ditches. To do this they must be spaced not more than one-half mile apart and usually they should be located in parallel lines. In building the levee around a district the resulting canal can sometimes safely be made on the inside of the levee and consequently used as a reservoir canal. On small districts this canal may be extensive enough to make up the entire reservoir-canal system. The practice of placing the levee canal inside the district has proved either a success or a failure, according to local conditions. If the berm between the levee and canal is wide, if the base is above ordinary stages of outside water, if there is no canal immediately outside the levee, and if the storm tide is low, such construction should not result in any great amount of seepage or subject the district to any danger from storm tide. On the other hand, if the canal is placed outside the district the seepage will be less, the levee will be safer in time of storm tide, and the canal can be used for navigation purposes. In all but the most favorable locations present practice tends toward placing the levee canal outside the district and cutting an interior system of reservoir canals.

The reservoir canal should be of such depth and cross section that the water will ordinarily be held at least 4 feet below the surface, although immediately after heavy precipitation the water may safely stand at the level of the lowest land for several hours. The reservoir canal serves a twofold purpose: (1) To take the water from the lateral ditches and carry it to the pumping plant, and (2) to store up the dry-weather flow of the ditches, so that the pumping plant will not need to be operated so frequently. Canals designed with only the first consideration in mind are smaller than when any considerable reservoir capacity is desired. If, however, the canals are correctly designed for storage capacity the question of flow will be taken care of. When heavy rains occur the storage capacity in the canals will take part of the run-off and temporarily relieve the pumping plant. Thus by an increase of reservoir capacity a less capacity of pumping plant will be required, and the plant can be operated more economically. The relative capacities of reservoir canal and pumping plant should be such that the interest and depreciation on the two investments, plus the cost of operation, would be a minimum. A complete set of records maintained on a number of typical reclamation districts for several years will be necessary before a relation can be established that would be capable of general application.

In some of the districts already constructed the reservoir capacity is about 0.6 inch in depth of water over the whole area. In these the average slope of the water surface in the canals is theoretically less than 0.2 foot per mile, with an average depth of flow of 6 feet and a run-off of 1 inch per day. If the reservoir capacity is so proportioned that the velocity of flow is nearly uniform in all parts of the system, the slopes can be held very close to the above figure. These slopes will of course increase when the water is lowered to near the bottom of the canals, but as the bulk of the water will be pumped at the time when the canals are full this increase of slope is not especially objectionable.

The local conditions will decide to some extent the question of using broad, shallow canals or deep, narrow ones. A broad, shallow canal has more of its

cross section available for storage, but after the water is reduced to 4 feet below the surface the slopes will greatly increase and trouble may be encountered in taking the water from the distant portion of the district. A minimum depth of about 7 feet seems to prove desirable in practice. This prevents vegetation from growing in the bottom of the canals and considerable silt deposits can be stored, so that the canals will not so frequently need to be cleaned. The canal should be gradually deepened as it nears the pumping plant to provide for the slope and consequent lowering of the water surface.

If the material taken from the reservoir canals is not to be used for levee construction and the land is free from timber and stumps, a hydraulic dredge is the most satisfactory means of cutting them. The unit price will then be lower on canals of a section exceeding 7 by 25 feet than if the work be done with another type of dredge and the canal will be better cleaned out and more permanent. Side slopes can be cut as desired with the hydraulic dredge and the material is deposited in a thin layer rather than in a high spoil bank. If the work is done in heavy timber a dipper dredge must be used, but if the growth is light either a dipper or an orange-peel-bucket dredge can be employed with the advantage in favor of the latter.

During the first few years after construction the maintenance charges on reservoir canals are quite high. A certain amount of bank caving occurs and a large amount of semifluid mud enters through the lateral ditches. The velocities of flow in the canals are not sufficient to transport any great amount of this material to the pumping plant. After the district is once thoroughly drained and cultivated the soil becomes more firm and very little material is then carried by the lateral ditches, as the average velocities of flow in them are very small. The canals can then be cleaned very satisfactorily with a small hydraulic dredge, as the material to be removed will usually be too soft for the dipper type of dredge.

PUMPING PLANT.

The drainage of low-lying wet lands by means of pumps has been described in a former publication of this office.[1] This publication discusses the general character of land drainage by means of pumps and deals especially with conditions in the upper Mississippi Valley. It is recommended that the reader obtain the above-mentioned bulletin. The general nature of this method of draining in southern Louisiana is much the same as described in this bulletin, but there are many differences in detail that deserve mention. These differences chiefly affect the capacity and operation of the pumping plant.

Necessary Capacity of Plant.

The general method of operation of plant in this part of the country is far different from that in the northern latitude, so, before discussing in detail such rainfall and run-off records as are available, it might be well to describe the usual method of operation.

In this latitude farming operations are conducted every month in the year. While general field crops are growing only about 9 or 10 months, the field must be kept sufficiently well drained to admit of cultivation at any time. The bulk of the heavy plowing is done during what are ordinarily called the winter months. The need of the pumps is therefore more or less continuous; that is,

[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 243.

the run-off at any time of the year must be taken out promptly. The influence of evaporation at different seasons of the year causes a great variation in the manner of operating the pumps. A heavy rainfall in summer necessitates continuous operation of the pumps for a period sufficient to empty the canals and ditches. The water that will continue to run out of the lateral ditches will often be more than balanced by the evaporation, so that it will not again be necessary to start the plant until another period of heavy precipitation occurs. Small local rains in summer will in all likelihood pass unnoticed. During the winter months a heavy precipitation necessitates a relatively longer period of pumping than in summer. Two or three days after the canals have been emptied the ground-water drainage entering through the lateral ditches will, owing to lack of evaporation, make it necessary to operate the plant for a few hours, and after an interval of about 10 days it will again be necessary to do some pumping, although no precipitation may have occurred during the intervening periods. If the reservoir capacity of the canals be small the operation of the pumping plant will be still more intermittent. If the plant is divided into two or more units, one unit only may be operated for the dry-weather run-off. The total time of pump operation during the year rarely exceeds 45 days of 24 hours each and often drops to as low as 15 days. The total number of days on which the pumps are operated average about 70.

In southern Louisiana most of the pumping plants so far installed have a theoretical capacity of at least 1 inch and many of them 1½ inches in depth of water over the inclosed area in 24 hours. The 1-inch run-off is equivalent to approximately 27 second-feet per square mile of area, or 0.042 second-foot per acre.

The necessary capacity of a pumping plant depends on the size and slope of the district to be drained, the depth and nature of the muck, the available storage capacity of canals and ditches, the system of lateral drains used, the method of operation of the plant, the character of the crops raised, and the amount and distribution of the rainfall. The proper allowance to be made for each of these factors can only be determined as the result of careful and complete observations in the field. Not only should the results for each district examined be carefully worked out, but the investigations should include a sufficiently large number of typical districts and should continue for such a length of time as to make the results of general application. Some of the above factors have been quite closely investigated over a few districts and all of them have been covered in a general way. While the results obtained are not final, the investigations still being carried on, these details will be discussed in the light of such investigations as have been made.

In planning gravity drainage districts it is customary gradually to decrease the run-off coefficient as the size of the district increases. With one exception the variation in size of the district in this section is as yet not great; therefore not much attention need be given this feature. In the summer, when rains are almost purely local, the larger district is not so likely to receive rains over its whole surface as is the smaller district. However, the rains that most heavily tax the pumping plant occur in the spring of the year and are general in character.

The variation in surface elevation on the average district is usually slight, but where the district fronts on a ridge having an elevation above the prairie land of from 8 to 12 feet it has been noticed that the lower lands become flooded and that the required capacity of pumping plant is nearly 50 per cent greater than on the flat lands. This flooding of the lower lands can be partly

overcome by a corresponding design of the various parts of the collecting system. By careful location of gravity outlet ditches this drainage water from the higher lands can in some cases be entirely diverted.

The character and depth of the layer of muck overlying the subsoil on these lands have a large influence on the run-off. The muck absorbs water very readily and if well drained to a depth of 3 feet its storage capacity is about 8 inches. When the land is first drained this muck will absorb water nearly as fast as the heaviest rate of precipitation, but as it decays and compacts both the storage capacity and the rate of absorption decrease very rapidly. A gradual increase in the rate of run-off must then be expected.

The effect of reservoir capacity has already been discussed. However, it might be well to point out that increase of reservoir capacity does not decrease the amount of pumping to be done, but simply acts to decrease the time of flooding in case the run-off overtaxes the capacity of the plant. The effect is relatively less on short violent periods of precipitation than on longer but equally heavy ones. This will be illustrated in the discussion of rainfall and run-off.

Deep lateral drainage acts to decrease the intensity of run-off. If such laterals are lines of tile, the rate of run-off will still further be decreased, for practically all water must then pass downward through the soil and out through the tile before it can reach the canal, while in the case of open field ditches most of the water can flow over the surface to the ditch and thus directly into the canal. Especially will this effect be noticed as the muck gradually loses its power of rapid absorption.

If the pumping plant be designed to operate continuously its capacity may be much less than that of a plant intended for day use only. As previously mentioned, there is need of the plant at all times of the year. The fact that the water is always promptly pumped out and that all reservoir capacity is quickly available makes a smaller plant capacity practicable.

Nearly all crops grown in this section are cultivated crops, so the rate of run-off will vary but little according to crop. However, the need for rapid removal of all rainfall is greater with truck crops than with general field crops such as cane or corn. With the former very little if any flooding of the surface is allowable, while with the latter the surface may be flooded for perhaps 24 hours several times a year without great damage. The character of crops to be grown should be known and considered in the design of the pumping plant.

The amount and distribution of the rainfall are the most important of all the factors in determining the required capacity of the pumping plant for a given area. While a knowledge of the total yearly and monthly amounts of rainfall, either maximum or average, is important in determining the probable total amount of water to be pumped each year or month, the distribution of the rainfall is the factor that fixes the necessary capacity; that is, the amount of water falling in a period of three or four days must be considered, rather than the amount falling in a year or a month.

On page 5 are tabulated the heaviest storms that have occurred at New Orleans during the past 22 years. It would not be profitable to provide sufficient pumping-plant capacity to care for the run-off of the maximum storm, but only for those that occur so frequently that the resulting damage would be larger than the interest on the additional investment needed to provide for them. By observing the rates of run-off on various typical districts it will be possible finally to determine the ratio that the run-off to be pumped bears to the amount of precipitation in the maximum storm. A determination can then be made of necessary plant capacity, after taking into consideration the factors previously mentioned.

In order to obtain the relation between rainfall and run-off for lands of this section, rain gauges were installed on a number of districts in June, 1909, and a careful log of pumping-plant operation has since been kept. The capacities of the various pumps were obtained by careful ratings. The three areas (Nos. 1, 2, and 8) on which these records were kept have already been described in detail. An examination of the descriptions will show that these districts vary widely in natural characteristics and in the nature of the improvements. In applying the results obtained to any other sections these local conditions should be considered. The daily records for the entire period will not be included here; only the records of heavy storms will be given, these latter being all that are required to determine the proper run-off coefficient. The run-off results vary so widely on the different tracts that they will be discussed separately, and the proper rate of run-off to be provided for will be determined in a preliminary way. It is to be understood, however, that these conclusions are not final and that records of rainfall and run-off extending over longer periods may lead to different ones.

The following table for area No. 2 gives the rainfall and run-off for the eight heaviest storms that occurred during the period, June, 1909, to May, 1912. The stages of water in the reservoirs above or below the general ground surface are given as of 8 a. m. and 8 p. m., these being the usual hours at which the plant was started and stopped when operating in daytime; of course during the heaviest storms considerable pumping was done at night. The condition of the soil at the time of the storm is also noted.

Rainfall, water pumped, and reservoir stages due to heaviest storms occurring on area No. 2, June, 1909, to May, 1912.

[Reservoir capacity, 0.45 inch. Pumping capacity, 1.11 inches.]

Date.	Rainfall.	Water pumped.	Stage of water in reservoir above (+) or below (−) general surface.		No. of hours land flooded.	Condition of soil before storm.
			8 a. m.	8 p. m.		
1909.	*Inches.*	*Inches.*	*Feet.*	*Feet.*		
June 1	0.65	0.00	Not recorded.		.....	Well drained, and one-third in cultivation.
2	4.20	.71				
3	.00	1.10				
4	.39	.40				
5	.00	.22				
Aug. 9	1.14	.00	−0.1	+0.1	18	Do.
10	1.68	.80	+0.2	−1.0		
11	2.80	.90	−2.0	0.0		
12	.02	.80	−0.3	−2.0		
13	.13	.40	0.0	−2.5		
Sept. 19	.65	.00	−0.3	−0.2	54	Do.
20	3.30	.33	−0.1	+0.3		
21	.00	.47	+0.6	+0.3		
22	.00	.72	+0.6	+0.1		
23	.00	.45	−0.4	−0.6		
24	.00	.23	+0.3	−0.2		
Dec. 11	2.80	.00	−1.0	0.0	40	Saturated, and one-third in cultivation.
12	.15	.63	+0.4	+0.2		
13	.00	.62	+0.2	−0.2		
14	.00	.42	+0.3	−1.0		
15	.00	.37	0.0	−2.6		
1910.						
July 1	.50	.15	−1.6	−2.7	36	Well drained, and two-thirds in cultivation.
2	1.82	.23	−2.0	−1.6		
3	3.40	.54	−0.6	−0.9		
4	.36	.77	+0.1	+0.1		
5	.05	1.06	+0.1	0.0		
6	.00	.70	−0.1	−0.7		
7	.00	.41	−1.3	−2.0		

Rainfall, water pumped, and reservoir stages due to heaviest storms, etc.—Con.

Date.	Rainfall.	Water pumped.	Stage of water in reservoir above (+) or below (−) general surface.		No. of hours land flooded.	Condition of soil before storm.
			8 a. m.	8 p. m.		
1911.	*Inches.*	*Inches.*	*Feet.*	*Feet.*		
Apr. 25	1.02	.00	−2.0	−1.8		
26	2.02	.56	−1.6	−1.2		
27	.00	.83	−0.5	−2.8	0	Well drained, and three-fourths in cultivation.
28	.22	.23	−1.8	−3.5		
Nov. 27	3.00	.47	−0.3	−0.2		
28	.00	.88	−0.6	−3.0	0	Do.
29	.00	.34	−0.3	−2.0		
1912.						
May 1	.30	.00	−3.3	−3.0		
2	.00	.00	−2.8	−2.7		
3	.41	.00	−2.6	−2.5		
4	.00	.00	−2.4	−2.3		
5	1.05	.00	−2.1	−1.6	0	Well drained, and seven-eighths in cultivation.
6	1.21	.55	−1.4	−0.6		
7	.00	.68	−0.5	−0.6		
8	.00	.56	−1.6	−2.6		
9	.00	.11	−2.6	−1.5		

From an examination of the above table it will be seen that it was only during four of these storms that flooding occurred. It is also apparent that if the plant had been operated at full capacity flooding would not have occurred during any of the storms. The flooding was due to unreliable machinery rather than to insufficient theoretical capacity; during the storms of September and December, 1909, the plant was operated at less than half its maximum capacity. In determining the proper capacity of plant to remove these heavy storms it will be necessary to consider only those of August, 1909, and July, 1910. The flooding that occurred on this tract due to these two storms was on only a relatively small portion in the immediate vicinity of the reservoir, and in neither case did it damage crops, as the water was only about 4 inches deep on the ground. In the storm of August, 1909, a pumping capacity of 0.85 inch would have been sufficient to prevent damaging overflow. The total water removed was 2.90 inches. By starting the pumps on August 9, or one day earlier than was done, a capacity of about 0.75 inch would have served to take away all drainage water in time to prevent flooding, as the water would all have been removed more than 24 hours sooner than actually occurred. In the storm of July, 1910, by starting a plant of a capacity of 0.75 inch on July 2 the run-off of the 2d and 3d could have been taken out on the 2d, thus making a gain of 24 hours. It is not possible to estimate exactly the effect of such a gain, but it would appear that the time of flooding would have been reduced to about 12 hours. By applying a pumping capacity of 0.75 inch per day to the other storm periods it will be seen that the run-off could all have been removed without flooding, although the reservoir probably would have stood nearly full for some days. This condition would be allowable two or three times a year without damage to crops. After a period of cultivation of several years the soil on this tract will become more impervious and the intensity of run-off will be greater.

Rainfall, water pumped, and reservoir stages due to heaviest storms occurring on area No. 1, June, 1909, to May, 1912.

[Reservoir capacity 0.34 inch. Pumping capacity 1.45 inches.]

Date.	Rainfall.	Water pumped.	Stage of water in reservoir above (+) or below (−) general surface.		No. of hours land flooded.	Condition of soil before storm.
			8 a. m.	8 p. m.		
1909.	*Inches.*	*Inches.*	*Feet.*	*Feet.*		
June 1	0.15	0.00	Not recorded.			
2	4.10	.84	−0.7	−0.1		
3	1.00	1.41	+.5	+.3	24	Well drained. All cultivated.
4	.00	.76	−3.0	−4.0		
5	.00	.23	−2.0	−4.3		
Sept. 20	4.14	.62	−1.5	−1.4		
21	.30	1.00	−2.2	−3.0	0	Well drained.
22	.00	.50	−2.0	−4.0		
Dec. 11	3.12	.00	−1.0	0.0		
12	.27	.96	+.6	+.6	40	Saturated.
13	.00	.90	+.3	−3.0		
14	.00	.26	−4.0	−1.5		
1911.						
Apr. 8	3.55	.47	−2.0	−1.0		
9	.00	1.26	−.8	−2.1		
10	.00	.32	−4.0	−2.0	0	Well drained.
11	.38	.59	−1.1	−3.0		
12	.00	.20	−2.0	−3.5		
Apr. 25	4.05	.65	−2.1	+1.0		
26	2.21	1.16	+1.0	+1.0		
27	.00	1.16	+.5	0.0	48	Do.
28	.00	.98	−1.0	−3.5		
29	.00	.21	−1.5	−3.0		
1912.						
Jan. 6	.22	.00	−1.6	−1.0		
7	2.18	.00	−.5	0.0	24	Saturated.
8	.60	1.16	+.4	+.5		
9	.00	1.11	−1.0	−3.5		
Mar. 22	1.70	.00	−2.0	−.4		
23	2.02	1.02	0.0	−.5	0	Well drained.
24	.00	.74	−.8	−1.0		
25	.00	.54	−1.5	−3.5		
Apr. 13	1.42	.55	−1.0	−2.0		
14	3.93	.48	−2.0	0.0		
15	.00	1.31	+1.0	+1.0	48	Do.
16	1.72	1.32	+.5	0.0		
17	.00	1.05	−1.0	−1.6		
18	.00	.37	−2.0	−2.0		
May 1	.26	.00	−1.7	−1.5		
2	.62	.35	−1.2	−3.5		
3	1.20	.60	−1.2	−1.0		
4	.00	.50	−2.1	−3.8		
5	2.00	.00	−2.0	−1.5		
6	.00	.64	−1.2	−1.1		
7	.00	.69	−2.5	−3.2	36	Do.
8	.00	.23	−2.0	−3.5		
9	.00	.00	−2.3	−2.2		
10	4.50	.45	−2.0	+.9		
11	.00	1.42	+1.2	+.6		
12	.00	1.43	0.0	−2.0		
13	.00	.26	−4.2	−3.5		

It will be noted that during six of the nine storms enumerated above flooding occurred. However, only the land immediately along the reservoir canal was flooded and no great damage resulted, i. e., crops were not killed.

In the detailed description of this district a number of conditions were mentioned that were responsible for these large rates of run-off. The small reservoir capacity places the pumping plant at a disadvantage during both heavy and ordinary storms. It allows no reserve in the first case and in the second the plant can not be operated at full capacity for lack of water; only one unit can well be operated continuously until the water is removed. The pumping plant on this tract has not yet failed to remove the water soon enough to prevent any considerable damage to crops. By increasing the storage capacity to

about 0.8 inch the present plant should work to much better advantage. The canal that brings the water from the "front" lands should not be enlarged, as the rapid run-off from these higher lands is at present largely responsible for the flooding. It is doubtful if even a large increase in pumping capacity would be effective if the present reservoir were not improved. With the reservoir enlarged to the usual size of those on other districts, the present pumping plant probably would be of sufficient capacity to give satisfactory drainage.

The drainage from area No. 8 is disposed of by gravity instead of by pumping. The internal canals are large and the outlet canal is of such size that, except in the case of extreme storms, the fluctuation of the water surface in the canals is small; that is, the water is discharged very soon after it reaches the canals. Twelve storm periods are included in the following table:

Rainfall and run-off due to heaviest storms occurring on area No. 8, December, 1909, to April, 1912.

[Gravity drainage system.]

Date.	Rainfall.	Run-off.	Condition of soil before storm.
1909.	*Inches.*	*Inches.*	
Dec. 11	0.00	0.06	Well drained.
12	2.74	.12	
13	.00	.34	
14	.80	.33	
15	.00	.32	
16	.00	.32	
17	.33	.31	
18	.12	.26	
19	.00	.21	
20	.00	.21	
21	.00	.20	
1910.			
Mar. 9	.00	.05	Dry.
10	3.11	.10	
11	.00	.18	
12	.00	.15	
13	.00	.12	
May 17	.00	.00	Very dry.
18	.21	.02	
19	2.83	.08	
20	.00	.06	
21	.27	.07	
22	1.57	.08	
23	1.25	.11	
24	.30	.14	
25	.00	.12	
July 17	.73	.12	Saturated.
18	.55	.12	
19	.65	.34	
20	.92	.39	
21	.17	.29	
22	.37	.23	
23	.20	.19	
1911.			
Mar. 21	.00	.02	Dry.
22	3.80	.36	
23	.00	.62	
24	.00	.37	
25	1.15	.38	
26	.00	.45	
27	.00	.38	
28	.00	.24	
Apr. 3	.00	.08	Well drained.
4	.10	.11	
5	1.10	.16	
6	.00	.12	
7	.00	.08	
8	4.03	.69	
9	.00	.98	
10	.00	.48	
11	1.15	.42	
12	.00	.49	
13	.00	.33	
14	.00	.25	

Date.	Rainfall.	Run-off.	Condition of soil before storm.
1911.	*Inches.*	*Inches.*	
Apr. 24	1.05	.12	Saturated.
25	.00	.11	
26	2.72	.59	
27	.50	.81	
28	.00	.73	
29	.45	.44	
30	.00	.40	
May 1	.99	.55	
2	.48	.50	
3	.18	.36	
4	.18	.28	
5	.00	.19	
Dec. 18	.00	.07	Well drained.
19	2.66	.08	
20	.00	.44	
21	.26	.34	
22	.85	.28	
23	.25	.38	
24	.00	.35	
25	.32	.27	
26	.13	.24	
27	.29	.23	
1912.			
Jan. 6	.13	.18	Saturated.
7	1.61	.17	
8	.80	.49	
9	.00	.58	
10	.00	.38	
11	.02	.28	
12	.00	.23	
Mar. 10	.00	.04	Well drained.
11	2.30	.12	
12	.00	.42	
13	.00	.30	
14	.45	.23	
15	.00	.20	
Mar. 21	.05	.08	Well drained.
22	3.60	.24	
23	2.40	1.09	
24	.00	1.78	
25	.00	.84	
26	.00	.42	
27	.00	.32	
28	.00	.25	
Apr. 11	.26	.07	Well drained.
12	1.39	.07	
13	.21	.17	
14	2.10	.71	
15	.00	1.42	
16	1.60	1.08	
17	.00	.69	
18	.00	.44	
19	.10	.31	
20	.37	.25	
21	.00	.20	

A wide variation in the rates and amounts of run-off is apparent from the above table, according to the distribution of the rainfall, the time of the year, and especially to the condition of the soil before the storm occurred. The soil is spongelike in its action, and the fact that there are few lateral ditches makes a condition favorable for a large absorption. During the heaviest storms the soil became saturated and the water flowed over the surface to the canals.

In case the run-off from this tract were handled by a pumping plant, the daily run-offs given in the above table would be the amounts available for pumping each day, and if cared for, either by pumping or by storing in a reservoir, flooding would not occur. Therefore by assuming a certain pumping-plant capacity the required capacity of reservoir can easily be determined for these storms and for this particular district. In the following tables different pumping-plant capacities have been assumed and the corresponding necessary reservoir capacities have been calculated. These calculations are based upon the storms of March and April, 1912, these having caused the heaviest run-off. This determination is not made with the idea that the results will be capable of general application, but rather for the purpose of showing a method of finding the proper pumping-plant and reservoir capacities for a given run-off.

Required reservoir capacities for different pumping-plant capacities on area No. 8.

BASED ON STORM OF MAR. 21–25, 1912.

Date.	Rainfall.	Run-off.	Plant capacity 1.4 inches—Water pumped.	Reservoir capacity 0.4 inch—Water in reservoir.	Plant capacity 1.2 inches—Water pumped.	Reservoir capacity 0.6 inch—Water in reservoir.	Plant capacity 1 inch—Water pumped.	Reservoir capacity 0.8 inch—Water in reservoir.	Plant capacity 0.9 inch—Water pumped.	Reservoir capacity 1 inch—Water in reservoir.	Plant capacity 0.8 inch—Water pumped.	Reservoir capacity 1.3 inches—Water in reservoir.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Mar. 21	0.05	0.08	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.08	0.00	0.08
Mar. 22	3.60	.24	.32	.00	.32	.00	.32	.00	.32	.00	.32	.00
Mar. 23	2.40	1.09	1.09	.00	1.09	.00	1.00	.09	.90	.19	.80	.29
Mar. 24	.00	1.78	1.40	.38	1.20	.58	1.00	.87	.90	1.07	.80	1.27
Mar. 25	.00	.84	1.22	.00	1.20	.22	1.00	.71	.90	1.01	.80	1.31
Mar. 26	.00	.42	.42	.00	.64	.00	1.00	.13	.90	.53	.80	.93
Mar. 27	.00	.32	.00	.32	.00	.32	.00	.45	.85	.00	.80	.45
Mar. 28	.00	.25	.57	.00	.57	.00	.70	.00	.00	.25	.70	.00

BASED ON STORM OF APR. 11–21, 1912.

Date.	Rainfall.	Run-off.	Plant capacity 1.4 inches—Water pumped.	Reservoir capacity 0.4 inch—Water in reservoir.	Plant capacity 1.2 inches—Water pumped.	Reservoir capacity 0.4 inch—Water in reservoir.	Plant capacity 1 inch—Water pumped.	Reservoir capacity 0.5 inch—Water in reservoir.	Plant capacity 0.9 inch—Water pumped.	Reservoir capacity 0.7 inch—Water in reservoir.	Plant capacity 0.8 inch—Water pumped.	Reservoir capacity 0.9 inch—Water in reservoir.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Apr. 11	0.26	0.07	0.00	0.07	0.00	0.07	0.00	0.07	0.00	0.07	0.00	0.07
Apr. 12	1.39	.07	.00	.14	.00	.14	.00	.14	.00	.14	.00	.14
Apr. 13	.21	.17	.00	.31	.00	.31	.00	.31	.31	.00	.31	.00
Apr. 14	2.10	.71	1.02	.00	1.02	.00	1.00	.02	.71	.00	.71	.00
Apr. 15	.00	1.42	1.40	.02	1.20	.22	1.00	.44	.90	.52	.80	.62
Apr. 16	1.60	1.08	1.10	.00	1.20	.10	1.00	.52	.90	.70	.80	.90
Apr. 17	.00	.69	.69	.00	.79	.00	1.00	.21	.90	.49	.80	.79
Apr. 18	.00	.44	.44	.00	.00	.44	.65	.00	.90	.03	.80	.43
Apr. 19	.10	.31	.00	.31	.75	.00	.00	.31	.00	.34	.74	.00
Apr. 20	.37	.25	.56	.00	.00	.25	.56	.00	.00	.59	.00	.25
Apr. 21	.00	.20	.00	.20	.45	.00	.00	.20	.79	.00	.00	.45

It will be noted from the foregoing table that the smallest reservoir capacity that is indicated is 0.4 inch in depth of water on the whole area. The size of canal necessary to bring the water to the plant rapidly enough to secure continuous operation and to keep the slope of water surface reasonably small will give a storage capacity of 0.4 inch. In the following summaries the estimated costs of pumping plants and reservoirs are given. The head on pump has been assumed at 6 feet, with 60 per cent efficiency of pump and 90 per cent mechanical efficiency of engine. The figures for cost of plant are for simple slide-valve noncondensing engines and have been taken from the curve in figure 18, which shows the average cost of pumping plants in this State under conditions similar to those on the tract in question. The cost of the reservoir has been calculated at 7 cents per cubic yard and includes only that part of the canal prism between the surface and a depth of 4 feet. It is assumed that the reservoir canal would not be widened below the 4-foot level.

Costs for necessary capacities.

STORM OF MAR. 21–28, 1912.

Capacity of reservoir.	Cost of reservoir.	Capacity of plant.	Cost of plant.	Total cost.
Inches.		*Inches.*		
0.4	$4,100	1.4	$7,000	$11,100
.6	6,100	1.2	6,100	12,200
.8	8,200	1.0	5,400	13,600
1.0	10,220	.9	4,900	15,120
1.3	13,600	.8	4,700	18,300

STORM OF APR. 11–21, 1912.

0.4	$4,100	1.4	$7,000	$11,100
.4	4,100	1.2	6,100	10,200
.5	5,100	1.0	5,400	10,500
.7	7,150	.9	4,900	12,050
.9	9,200	.8	4,700	13,900

It appears from the above estimate that the cheapest improvements to take care of the storm of March 21–28, 1912, would be a combination of a plant capacity of 1.4 inches and a reservoir capacity of 0.4 inch, and that for the storm of April 11–21, 1912, there should be a plant capacity of 1.2 inches and a reservoir capacity of 0.4 inch. Excepting in the first case, the cost of providing for the second storm is less in each capacity of plant than for the first storm. While the run-offs from these two storms were nearly the same, the time over which the second was distributed was greater, thus allowing smaller capacity of reservoir.

Although as regards first cost alone it appears that the larger plant and small reservoir should be used, there are other factors that enter into the problem. The larger canals would decrease the lift of the plant, as the slope in water surface during operation would not be so great as in the small canals. The operation of the plant, in pumping from a large canal, would not be so intermittent as from a small canal; this would make for better fuel economies. The rate of interest on plant and on reservoir would be the same, but the percentage to be allowed for depreciation and repairs probably would differ somewhat. In removing the run-off from a given storm the smaller plant would have to operate longer, thus increasing the labor charges over those of the larger plant. To determine the proper weight to be given these various factors, continued and detailed records on a number of typical districts are needed, but they are here mentioned to make clear the fact that there are other features

besides the first cost of the improvements to be considered in fixing the proper relative capacities.

Location, Design, and Construction of Plant.

Theoretically the plant should be so located that the water in coming to it will travel the minimum length of reservoir canal. This condition usually would be met if the plant were placed in the center of the district and discharged through a leveed outfall canal to some bordering lake or bayou. In practice, however, the plants ordinarily are located on one side of the tract and on some navigable lake or bayou. This greatly facilitates the transportation of heavy machinery during the erection of the plant, as the ground usually is much too soft to allow the hauling of heavy loads. Fuel also can then be transported cheaply. If the tract has any considerable slope in its surface the logical location of the plant is in the lowest part. However, this part is often very soft, and to secure foundation it may be advisable to locate in some higher and more stable portion. As pointed out in the discussion of levees, there are frequent ridges of silt winding through these swamps, and a plant can often be located on one of these solid ridges. While it would be necessary to use a great many piles under the foundation in either case, the number can be reduced if the plant is located on a ridge.

The foundation under both the machinery and the building of these plants should be of concrete, well supported by piling. A plan of the foundation under the plant at Gueydan has already been shown (fig. 16, p. 51) and is a good illustration of a foundation in this character of soil. The foundation under the plant on area No. 5, already illustrated (fig. 13, p. 45), is also a good one. It will be noted on both these plans that the foundation is surrounded by sheet piling and that under the center of the Des Allemands plant a line of sheet piling has been driven and extended into the concrete. In these soft soils such precautions are necessary. The engine and pump usually are mounted on the same block of concrete, so that any subsequent settlement will not throw them out of line. While buildings to inclose the machinery should be of durable and fireproof construction, they are not called upon to protect the machinery and attendants from low winter temperatures. A frame of structural steel covered with heavy corrugated galvanized iron answers the purpose very well, although in one case a brick building has been erected. These buildings should be capable of resisting the action of the tropical hurricanes, for it is at such times that the need for the plant is greatest.

The selection and arrangement of machinery in centrifugal pumping plants have already been discussed in detail in publications of this office.[1] While the local conditions considered in these publications are somewhat different from those in southern Louisiana, the same principles are involved, and the same general features are to be considered.

As stated previously, the average lift of drainage pumping plants is from 3 to 10 feet. The bulk of the water is lifted little more than 3 feet. Special attention should therefore be given to the reduction of all friction and velocity head losses to a minimum, as a poor arrangement of piping on the pumps may easily double the total head against which they must work. The design of the pump must be especially suited to such low and variable lifts in order to give efficient service, the ordinary centrifugal pump for higher lifts being very inefficient under these local conditions. These pumps should also be so designed that they are able to work under an overload. Increased capacity can then be

[1] U. S. Dept. Agr., Office of Expt. Stas. Bul. 243, Land Drainage by Means of Pumps, by S. M. Woodward; Circ. 101, The Selection and Installation of Machinery for Small Pumping Plants, by W. B. Gregory.

secured by speeding up the pump. The efficiency will be less when working under an overload, but this increased capacity at times of heavy precipitation is very desirable, even if secured at a sacrifice of efficiency. The rated capacity of ordinary centrifugal pumps is based on a velocity of flow, through the discharge opening on the pump, of from 10 to 12 feet per second. Pumps are now being designed to increase this velocity to 14 or 15 feet per second when run at high speeds, i. e., overloads. This will make possible the installation of smaller pumps.

Another point that must be considered in the design of both engine and pump is the gradual increase in static lift that may be expected, due to the subsidence of the muck soils. Of course the amount of this subsidence will depend upon the nature and depth of the original muck, but it will often amount to 2 or even 3 feet in the course of 10 or 15 years. Both the average and the maximum lift will thus be increased by this amount. After a period of perhaps 15 years further subsidence will amount to little.

The total amount of water pumped in a year will affect the character of machinery to be used. The rainfall in this section is greater than in the northern latitudes, and the run-off, consequently, is also greater. The following table gives the yearly rainfall and run-off on three of the districts previously described, and the number of days on which rainfall and pumping occurred for the period from June, 1909, to May, 1912, inclusive.

Yearly and average yearly rainfall, run-off, number of days on which pumps were operated, and number of days on which rain fell on areas Nos. 1, 2, and 8, June, 1909, to December, 1912.

Year.	Area No. 1.				Area No. 2.				Area No. 8.		
	Rainfall.	Run-off.	Number of days. pumps ran.	Number of days rain fell.	Rainfall.	Run-off.	Number of days pumps ran.	Number of days rain fell.	Rainfall.	Run-off.	Number of days rain fell.
	Ins.	*Ins.*			*Ins.*	*Ins.*			*Ins.*	*Ins.*	
1909[1]	42.32	16.33	45	66	37.21	15.83	41	57	27.74	9.98	62
1910	43.08	11.58	45	83	41.48	10.83	55	84	[2] 42.54	[2] 15.77	[2] 68
1911	52.32	23.41	69	75	54.56	25.84	102	96	62.22	32.69	108
1912	[3] 48.22	[3] 34.42	[3] 81	[3] 48	58.86	[4] 50.34	131	91	65.72	40.59	120
Total	185.94	85.74	240	272	192.11	102.84	329	328	198.22	99.03	358
Average, year	57.21	26.38	74	84	53.36	28.57	91	91	59.53	29.80	108

[1] June to December, inclusive.
[2] February, September, and October omitted.
[3] June to September, inclusive, omitted.
[4] Large run-off due to excessive seepage through levees.

The above table would indicate that an average run-off of about 28 inches per year might be expected and that it would be necessary to operate the pumps on from 70 to 90 days a year. During the 3 years and 7 months that the records were kept the boilers of the plant on area No. 2 were fired up 278 times, and those on area No. 1 189 times in 3 years and 3 months. The average number of times that these boilers were fired per year was 68. This yearly average is higher than should be expected on districts with larger reservoir capacities.

Cost of Pumping Plants.

The cost of drainage pumping plants per indicated horsepower varies widely according to type of machinery, expense of transportation of machinery to site of plant, character of foundation, and difficulty of erection. The last three

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items will vary greatly according to local conditions. An accompanying diagram (fig. 18) shows comparative approximate costs of single-unit centrifugal pumping plants erected complete, inclusive of foundations, but exclusive of buildings, intake, discharge canals, or flume. These costs are based on estimates for work in Louisiana and Texas, and the diagram is published by courtesy of Mr. H. L. Hutson, of A. M. Lockett & Co. (Ltd.), New Orleans, La. These figures are approximate, but are on the safe side, i. e., they take into consideration construction under unusual difficulties. In making up these costs it was assumed that the effects of the three items which are mentioned as varying according to local conditions would be a constant percentage of the cost of the plant. It is obvious that this diagram should not be used for accurately obtaining the cost of a drainage plant, but that its chief usefulness is in showing the relative cost of the various types of machinery, for deciding upon the most economical size of unit to be used in large plants, and for making approximate estimates of the total cost of plants.

In making the diagram the cost of the plant has been divided into the cost of the "water end," being pump, pump foundation, and piping; and the cost of the "steam end," which includes the engines, boilers, and their foundations and auxiliaries. The cost of the water end is given in terms of gallons per minute of rated capacity, and that of the steam end in terms of indicated horsepower. Owing to the variation in costs, it is necessary to use zones instead of lines to indicate them.

The zone marked "Steam end, compound condensing Corliss or 4-valve engines," includes the cost of this type of engine and water-tube boilers. The zone marked "Compound condensing slide valve" includes the cost of this type of engine and either water-tube or return tubular boilers, according to the size of plant. The zone marked "Simple slide-valve noncondensing" includes the cost of this type of engine and horizontal return tubular boilers. It will be noted that for the higher class engines the cost is not indicated below about 100 horsepower, as engines of this class can not be purchased in smaller sizes than 75 or 100 horsepower.

In estimating the cost of a plant the following steps are necessary. With a given capacity of plant in gallons per minute, estimate the cost of the water end by use of the water-end zone. In order to get the cost of the steam end the indicated horsepower must first be calculated. The water horsepower is first determined, knowing the capacity and lift of the plant; this is then divided by the combined efficiency of the engine, transmission, pump, and piping, which will give the indicated horsepower. By using the various zones of cost of different types of engines, the cost of the steam end can be determined. Then by combining the cost of water end and steam end the total cost of plant will be determined.

Cost of Operation.

Full and complete records of pumping operations have not been kept on any district in this section until the present investigation was started in June, 1909. The records of cost of operation are therefore incomplete, and those that have been given are useful in illustrating the need for more efficient machinery rather than as serving as a guide for estimating the cost of operation of drainage plants in this section. On page 78 is a statement showing the comparative fuel costs of several types of pumping plants when removing 12 inches of water from a tract of 1,000 acres at the rate of approximately 1 inch per 24 hours against a total head on pump of 8 feet. This table and the one on page 80 have been prepared by A. M. Lockett & Co. as being applicable to local conditions and are published by their courtesy.

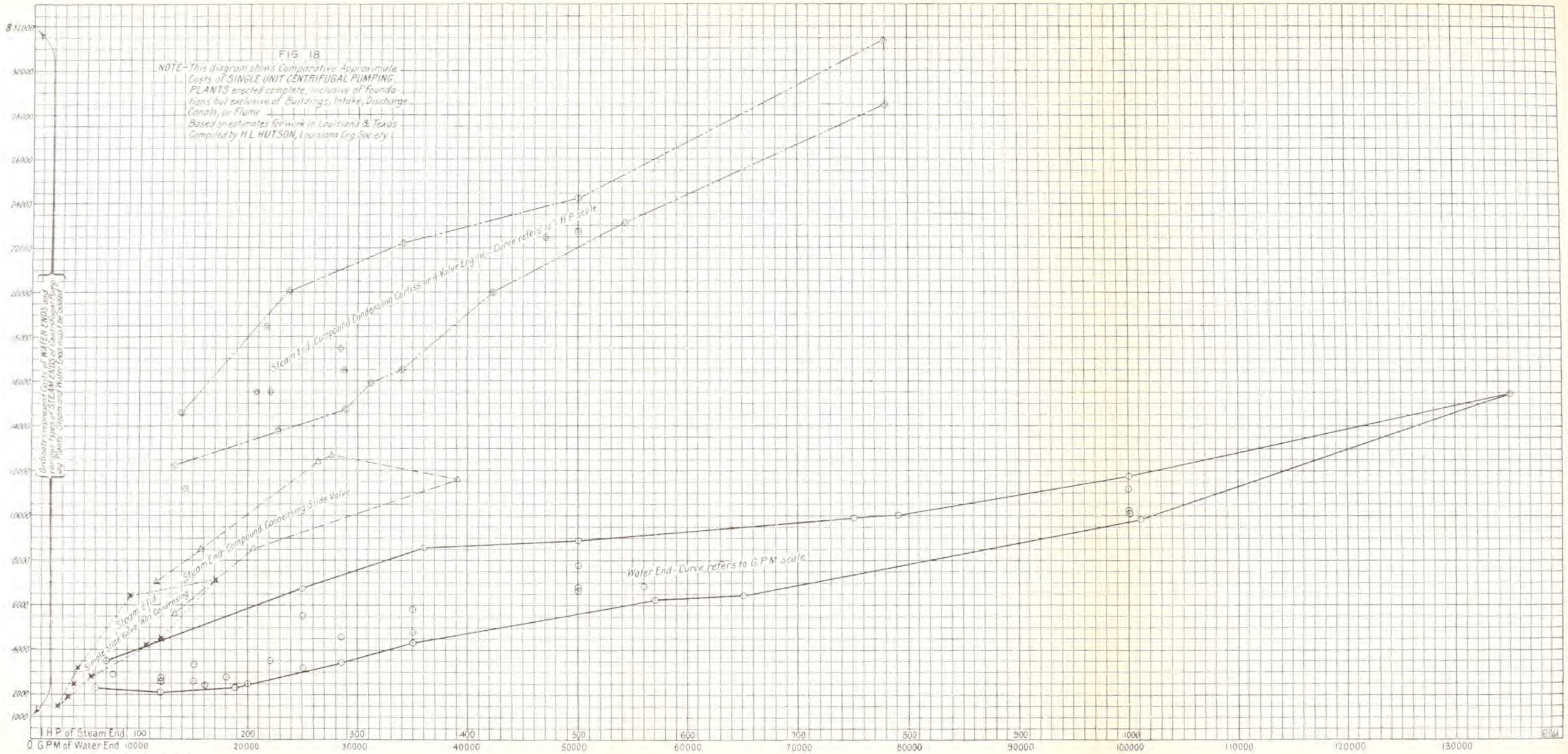
FIG 18
NOTE - This diagram shows Comparative Approximate Costs of SINGLE UNIT CENTRIFUGAL PUMPING PLANTS erected complete, inclusive of Foundations but exclusive of Buildings, Intake, Discharge Canals, or Flume
Based on estimates for work in Louisiana & Texas
Compiled by H L HUTSON, Louisiana Eng Society
Ordinates represent Costs of WATER ENDS and various types of STEAM ENDS of Centrifugal Pumping Plants. Steam and Water Ends must be added
Steam End Compound Condensing Corliss and Valve Engine - Curve refers to I H P Scale
Steam End Compound Condensing Slide Valve
Steam End Simple Slide Valve Non Condensing
Water End - Curve refers to G P M Scale
$32000
30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
1000
I H P of Steam End 100
200
300
400
500
600
700
800
900
1000
0 G P M of Water End 10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000

Comparative statement showing relative fuel costs of several types of pumping plants. For 1,000 acres, 6 feet difference in levels, 8 feet total head. Amount pumped=1 acre-foot per acre per season, at rate of approximately 1[1] acre-inch per acre in 24 hours.

[Prepared by A.M. Lockett & Co., New Orleans, La.]

Water horsepower.	Type of plant.	Efficiencies.			I. H. P. of steam engine; B. H. P. of gas engine.	Water rate of engine.	Total steam, including 20 per cent for auxiliary and oil burners.	Total fuel oil at 12 pounds evaporation.	Total gasoline at 1 pint per B. H. P. hour.	Total cost of fuel oil per hour at $1.25 per barrel.	Total cost of gasoline per hour at 12 cents per gallon.	Total fuel cost per year reclaiming and maintaining drainage on basis of removing total 12 inches at pump efficiencies named.										
		Engine.	Belting.	Combined.								100 per cent.	75 per cent.	70 per cent.	65 per cent.	60 per cent.	55 per cent.	50 per cent.	45 per cent.	40 per cent.	35 per cent.	30 per cent.
		P.ct.	*P.ct.*	*P. ct.*	*H.P.*	*Lbs. per I.H.P. hr.*	*Lbs. per hr.*	*Lbs. per hr.*	*Gals. per hr.*													
41	Simple slide-valve engine, belted	90	90	81	50.5	45	2,726	227	.....	$0.88	.....	$238	$317	$340	$366	$397	$433	$476	$529	$595	$680	$795
41	Simple slide-valve engine, direct connected	90	....	90	45.5	45	2,456	205	.....	.80	.....	218	290	311	336	364	396	436	485	545	623	727
41	Gasoline engine, belted	....	90	.....	45.5	.....	.....	.....	5.68	.....	$0.68	184	245	263	283	307	335	368	410	460	526	613
41	Gasoline engine, direct connected	....	....	.....	41.0	.....	.....	.....	5.11	.....	.61	165	220	236	254	275	300	330	366	412	471	550
41	Simple Corliss engine, belted	92	90	82.8	49.5	26	1,544	128	.....	.50	.....	135	180	193	208	225	246	270	300	338	386	450
41	Simple Corliss engine, direct connected	92	....	92	44.5	26	1,388	115	.....	.45	.....	122	163	174	188	203	222	244	271	305	350	407
41	Compound condensed slide valve, direct connected	90	....	90	45.5	20	1,092	91	.....	.36	.....	98	131	140	151	163	178	196	217	245	280	326
41	Compound condensed Corliss, direct connected	92	....	92	44.5	18	961	80	.....	.31	.....	83	111	119	128	138	151	166	184	208	237	276

[1] Specifically, 1.06 acre-inches.

As the headings in the table on page 78 are necessarily much abbreviated a short explanation of those that may seem obscure will be given. The first column gives the water horsepower of the plant of the assumed capacity. The second column states the type of plant, and also whether the engine is belted or direct connected to the pump. Under efficiencies, the third column gives the mechanical efficiency of the engine, the fourth that of the belt, if any, and the fifth the combined efficiency of engine and belt. The sixth column gives the indicated horsepower of the steam engine and the brake horsepower of the gasoline engine. The seventh column shows the pounds of water consumed by the engine, in the form of steam, per indicated horsepower hour; then the total steam used per hour would be the product of the two next preceding columns, plus 20 per cent for use of the usual auxiliaries and oil burners; these figures are shown in column 8. The ninth column gives the amount of fuel oil per hour necessary, assuming that 1 pound of oil will evaporate 12 pounds of water. In like manner column 10 indicates the number of gallons of gasoline required per hour, on the basis of 1 pint of gasoline per brake horsepower hour. The total cost of the fuel per hour (columns 11 and 12) is found by multiplying the total amount used per hour by the unit cost, which is here taken as $1.25 per barrel of 320 pounds for the fuel oil and 12 cents per gallon for the gasoline. The total cost per year is found by multiplying the cost per hour by 270, this being the number of hours the plant will be required to run to remove a depth of 1 foot of water from the 1,000 acres. Under this heading the first column gives the cost for a pump efficiency of 100 per cent. The figures in the other columns are derived by dividing the first column by the various pump efficiencies.

It will be noted in the above table that efficiencies of pumps are given from 30 to 100 per cent. Of course, the higher limit will never be attained, but the lower one doubtless will be reached when such pumps are worked under a heavy overload. The usual efficiency for average-size plants probably will vary between 55 and 65 per cent. In using this table it must be remembered that the higher-class engines can not be purchased in smaller sizes than 75 horsepower.

In the following table the above summary has been applied to a special case of a tract of 3,500 acres, showing the fuel costs per year for removing depths of water from 2 to 6 feet at the rate of 1 inch in depth per 24 hours. The greater depth of water might be encountered when the tract is first reclaimed, but the usual rate would be about 24 inches in depth per year.

Example of application of comparative statement to special case of 3,500-acre tract, 6 feet difference in levels, estimated total head 8 feet.

[Prepared by A. M. Lockett & Co., New Orleans, La.]

Type of plant.	Total cost of fuel per year at stated run-off.				
	72-inch.	60-inch.	48-inch.	36-inch.	24-inch.
Simple slide-valve engine direct connected to cheap open impeller pump, 40 per cent efficiency	$545×6×3.5=$11,440	$545×5×3.5=$9,540	$545×4×3.5=$7,630	$545×3×3.5=$5,720	$545×2×3.5=$3,815
Same, with 65 per cent efficiency pump	$336×6×3.5= $7,055	$336×5×3.5=$5,880	$336×4×3.5=$4,704	$336×3×3.5=$3,528	$336×2×3.5=$2,352
Compound condensing slide-valve direct connected to 65 per cent efficiency pump	$151×6×3.5= $3,171	$151×5×3.5=$2,642	$151×4×3.5=$2,114	$151×3×3.5=$1,585	$151×2×3.5=$1,057
Saving by using different types of plant	$11,440−$7,055=$4,385 $11,440−$3,171=$8,269 $7,055−$3,171=$3,884	$9,540−$5,880=$3,660 $9,540−$2,642=$6,898 $5,880−$2,642=$3,238	$7,630−$4,704=$2,926 $7,630−$2,114=$5,516 $4,704−$2,114=$2,590	$5,720−$3,528=$2,192 $5,720−$1,585=$3,606 $3,528−$2,192=$1,336	$3,815−$2,352=$1,463 $3,815−$1,057=$2,758 $2,352−$1,057=$1,295

The last column in this table shows that for removing a 24-inch depth the saving in fuel per year in using a compound condensing slide-valve engine instead of a simple slide-valve engine with the same pump would be $1,295. The labor charges for operating the two plants would be about equal, and an examination of the diagram of cost (fig. 18, p. 77) will show that the first cost of the plants would be very nearly the same and would be approximately $13,000. The interest and depreciation charges at 13 per cent would be $1,690 per year, which, added to the fuel cost of $1,057, would make for the compound-condensing type a total charge per year of $2,747, exclusive of labor. This is equivalent to a charge of $0.78 per acre per year. Labor charges would bring this up to about $1.06 per acre per year. On districts where the service is very intermittent or that are much smaller than this one, the fuel and labor charges would be relatively larger.

As mentioned above, few pumping districts are keeping careful and complete records of operation of plant. Without such records it is impossible to tell whether or not the plant is being run economically or to ascertain sources of waste. From the standpoint of the owners of the land such records are as essential as are the accounts of any business concern to its proprietors. These records are also essential to the future intelligent design of similar plants. If any progress is to be made in the matter of design and construction, not only of the pumping plant but also of the reservoir system, careful and complete records must be kept. This need of records is more essential for purposes of design and construction than for securing careful operation, because a system that is poorly designed to meet local conditions can never be satisfactory even if operated ever so carefully. The individuals and districts that are interested in drainage by pumping owe it to the future success of this form of reclamation and to their own self-interest to keep such records, for it is possible that much money can be saved in first cost of improvement, as well as in reduced operation charges.

Thus far, in the absence of detailed and reliable data, the design of plant has been based on a number of reasonable assumptions. However, when there is such a variation in these assumptions that the resulting plants for similar districts vary in capacity from 50 to 100 per cent, and in character from the lowest to the highest grade machinery, it is evident that a larger percentage of actual facts is needed as a basis of design in place of so much that is assumed. Owing to a variation in local conditions from one district to another, the records should be extended over a large number of typical districts, and it would be much better if a complete record could be secured from every pumping plant of importance. A few dollars spent in keeping such records will be worth many times the amount to each individual district, and the benefit in general to the work of drainage by pumping will be far-reaching and lasting.

The following form is recommended as one including the essential features of daily operation of plant.

Form for daily pumping records.

Date, ...

Hour.	Reservoir gauge.	Outfall gauge.	Speed of pump.	Steam pressure	Oil meter.	Rainfall.	Remarks.

It would be well to use one page for each day. The gauges in reservoir and outfall canal should be read before starting and again about one-half hour after starting. If practicable they should be read once an hour during operation and all other items should be so entered. It would also be well to read the oil meter, when oil is burned, before firing the boiler and again after the pumps are started. This will determine the losses due to intermittent operation, a question that is at present a subject of much discussion. If coal or wood is burned, it will not be so convenient to determine the amount consumed, but it should be estimated at least once a month. Other expenses should be carefully recorded and the total expenses of operating a plant should be classified under the following headings: Fuel, labor, supplies, repairs, and superintendence. The records should be kept in such form that the totals for month and year can easily be obtained. The cost per acre per year can then be determined, but to determine the cost of removing a given depth of water over the tract the pumps must be carefully rated. The above form provides for such data that the amount of water pumped can be calculated. If these records are faithfully kept on a large number of districts for a term of years, the resulting data will enable the engineer to design a pumping plant intelligently and with the knowledge that it will give satisfaction, not only in capacity, but in economy.

ACKNOWLEDGMENT.

It is with pleasure that acknowledgment is here made of the helpful spirit of cooperation displayed by railroads, companies installing drainage systems, landowners, and practicing engineers. Almost without exception these have cheerfully cooperated in the investigations and have done much to extend the scope and increase the accuracy of the work.

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